EVALUATION OF THE EDMONDS MARSH ESTUARY RESTORATION PROJECT

PREPARED FOR

Edmonds City Council
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Acronyms

BNSF	Burlington Northern Santa Fe
City	City of Edmonds
DO	dissolved oxygen
dSAY	discounted service-acre year
GIS	geographic information system
Hatchery	Willow Creek Fish Hatchery
HEA	Habitat Equivalency Analysis
LiDAR	light detection and ranging
LWD	large woody debris
Marsh	Edmonds Marsh
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NRD	natural resource damages
NRDA	natural resource damages assessment
Project	Edmonds Marsh Restoration Project (Willow Creek Daylighting)
USFWS	US Fish and Wildlife Service
WRIA	Watershed Resources Inventory Area

Executive Summary

The Edmonds Marsh (Marsh)—the only remaining salt marsh within the nearshore habitat zone of Watershed Resources Inventory Area (WRIA) 8 (the Lake Washington/Cedar/Sammamish Watershed) (SRFB 2014, 2018)—provides important habitat for birds and other wildlife. The City of Edmonds (City) is planning to conduct the Edmonds Marsh Estuary Restoration Project (Project) in the near future in order to daylight (i.e., bring aboveground) Willow Creek downstream from the Marsh, and to achieve other restoration enhancements within the Marsh. The Project will provide an array of enhancements to the current ecological functions of the Marsh, its tributary creeks, and adjacent buffer areas. It will create a sinuous, daylighted channel that flows downstream from the Marsh to Puget Sound; a new wetland area; new and enhanced riparian buffer habitats; and restored tidal/stream channels within the eastern portion of the Marsh. The Project will allow salmon and other migratory fish to once again access the Marsh and will increase the value of the Marsh for birds and other wildlife.

The purpose of this document is to describe the development of an ecosystem services model that was used to help estimate the ecological impact of the Project based on improved habitat functions. The input parameters necessary for the model included:

- The baseline condition and existing types and sizes (acreage) of habitats present within the restoration project footprint
- An estimate of the types of habitats that will be created/restored, and an estimate of the post-restoration sizes (acreage) of those habitats
- The relative habitat value associated with each habitat type
- The start and completion dates of on-site restoration activities
- The anticipated time it will take for the new/restored habitats to mature and become fully functional
- The anticipated lifespan of the restoration project
- A real discount rate (applied as in the science of economics) to translate future value into present-day value (this rate is estimated based on published literature and is typically set at 3%)

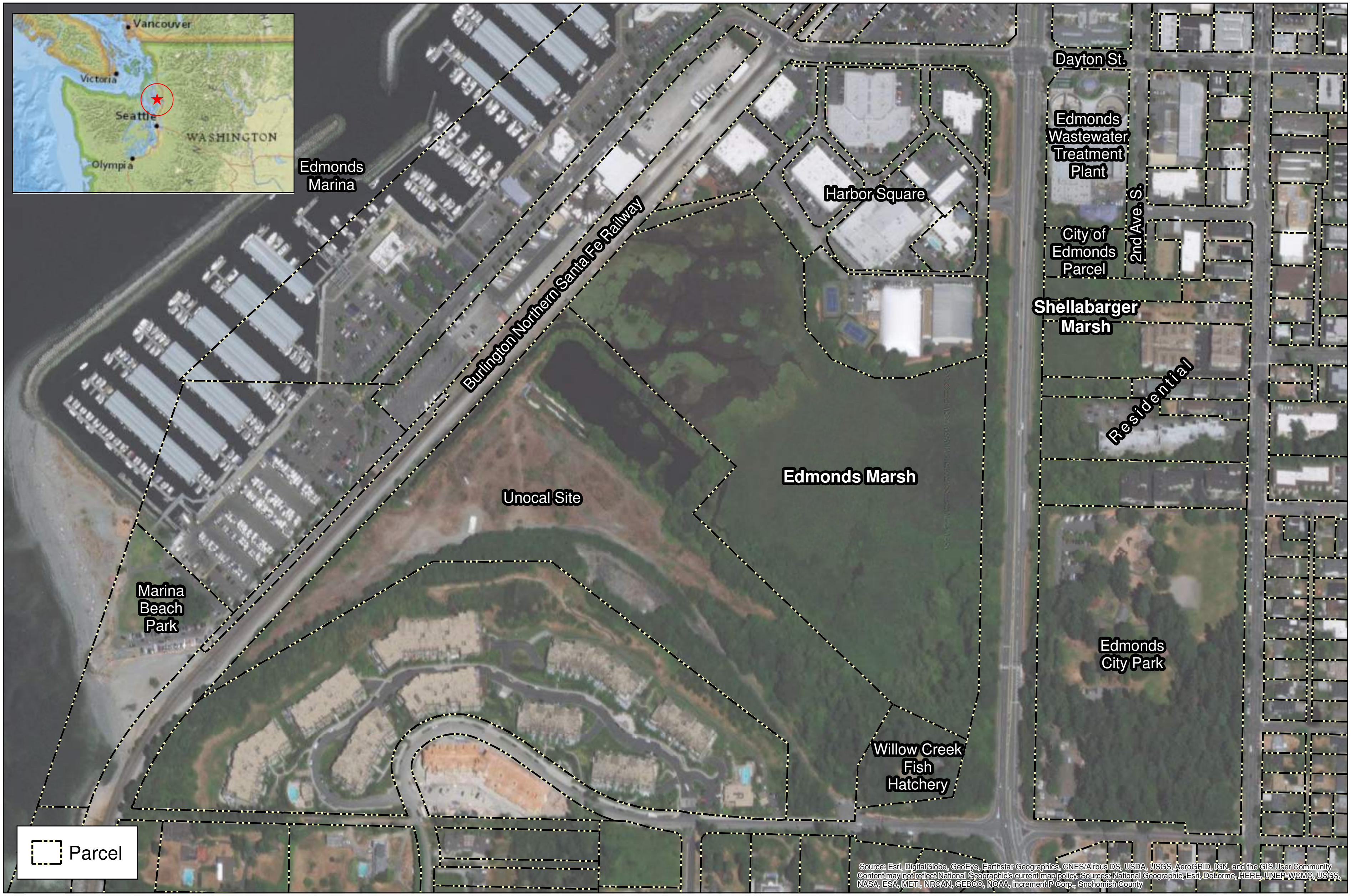
The input parameters were determined using a number of sources, including the Willow Creek daylighting feasibility studies (Shannon & Wilson 2015, 2019b), information collected to date as part of the Marsh baseline study (Windward 2018), and aerial photographs. Site-specific habitat values (or scores) were developed for the Marsh and its tributary creeks by considering the specific habitat requirements of species known to use the Marsh and/or its tributary creeks in their current conditions, or that would be expected to use the restored habitats after Project implementation. Based on model analysis, the Project has the potential to increase the level of ecosystem services provided by the Marsh and its tributary creeks by approximately 62%. In addition, implementing the Project would protect the current level of functions being provided by the Marsh.

The latter sections of this document provide initial recommendations for habitat features that could be incorporated into the Project design, such as quantities and anchoring techniques for large woody debris (LWD), suitable native plants for installation in riparian buffer areas, and invasive species control methods. Monitoring methods that could be employed post-restoration to track changes in habitat conditions and fish and wildlife use of the Marsh are also discussed.

1 Introduction

The Edmonds Marsh (Marsh) is a tidally influenced[1] wetland occupying approximately 29 acres in the heart of Edmonds, Washington (Figure 1); it is the remnant of a much larger estuarine wetland that was once located along the shores of Puget Sound (Sea-Run Consulting et al. 2007). Historically, the Marsh was a pocket estuary more than 100 acres in size and protected by a barrier sand spit (Shannon & Wilson 2015). It extended from Point Edmonds (located at the southern end of Marina Beach Park) north to Brackett's Landing near the Washington State Department of Transportation ferry terminal.

[1] The Marsh is tidally influenced when the tide gate downstream of the Marsh is open, typically in the spring and summer months. Since 2018, the City of Edmonds (City) has opened the tide gate for periods of time throughout the fall and winter months, tides and storm flows permitting, to allow tidal influx into the Marsh during these months as well.



Prepared by mikey, 5/14/2019; W:\Projects\Edmonds Marsh\Data\GIS\Maps and Analyses\Buffer_Zone_Evaluation\Fig 1-1_6862_Edmonds and Shellabarger Marsh Vicinity Map.mxd

Windward environmental LLC

N

0 0.05 0.1 Miles

0 400 800 Feet

Figure 1. Edmonds and Shellabarger Marshes vicinity map

The western portion of the Marsh contains mudflat habitat and tidal channels and supports salt marsh plants (Figure 2). When the tide gate is open, salinity in this portion of the Marsh typically ranges from approximately 1 to 25 parts per thousand.[2] The eastern portion of the Marsh is a predominantly freshwater system fed by two tributary creeks—Willow Creek and Shellabarger Creek (Figure 1). Table 1 provides the acreage of existing habitat types and features within the Marsh and Willow Creek Fish Hatchery (Hatchery).

Table 1. Acreages of existing habitat types/features within the Marsh and Hatchery

Habitat Type/Feature	Existing Acreage
Intertidal mudflat/shallow subtidal slough/estuarine marsh complex (western lobe of Marsh)	7.7
Freshwater, cattail-dominated area including scrub-shrub habitat islands and borders (eastern lobe of Marsh)	21.5
Hatchery (riparian and buffer habitat)	1.7
Willow Creek channel within Hatchery	0.1
Channelized Willow Creek within/adjacent to Marsh	0.4
Linear, daylighted portion of Willow Creek downstream from Marsh	0.6

Note: Some acreages were estimated using aerial photo imagery and/or GPS data obtained as part of the baseline study. The acreage of the creek channels within the Hatchery was estimated using the lengths of the channels and a width ranging from approximately 1 to 2 m (4 to 6 ft).

Hatchery – Willow Creek Fish Hatchery

Marsh – Edmonds Marsh

[2] Range is based on data collected as part of the baseline study between August and October 2018.

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N

0 0.05 0.1 Miles

0 200 400 Feet

- Major vegetation transition line
- Storm culvert
- Storm line
- Storm ditch/creek*
- Parcel
- City of Edmonds boundary

*Note: Shellabarger and Willow Creeks no longer flow through defined channels in the eastern portion of the marsh; however, their previous flow paths are shown.

Figure 2. Existing conditions

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The drainage basin of Willow Creek is approximately 393 acres in size and encompasses residential land to the south and east of the Marsh (Shannon & Wilson 2015; SAIC and Herrera 2013). Willow Creek enters the Marsh as two separate branches, flowing into the southeastern side of the Marsh via Hatchery property (Figure 1). Upon entering the emergent portion of the Marsh, Willow Creek flows in an unconfined flow path (i.e., not contained within a distinct channel) for a short distance before re-entering a linear channel at the south side of the Marsh (Figure 2). The drainage basin of Shellabarger Creek is approximately 378 acres in size and encompasses dense residential developments to the north, east, and south of the Marsh (SAIC and Herrera 2013). Shellabarger Creek flows through Shellabarger Marsh and other privately owned residential properties to the south of Shellabarger Marsh before passing through the SR 104 culverts into the Marsh. Upon exiting the culverts, Shellabarger Creek also flows in an unconfined path through dense Marsh vegetation (predominantly cattails [*Typha latifolia*]). Including the two creeks and other areas that discharge surface water to the Marsh, the drainage basin of the Marsh is approximately 900 acres in size.

The Marsh is connected to Puget Sound via Willow Creek, which currently flows out of the Marsh into an approximately 670-m-long (2,200-ft-long) system of ditches, pipes, culverts, and flood gate infrastructure prior to discharging into Puget Sound via a submerged outfall. The City is planning to conduct the Edmonds Marsh Estuary Restoration Project (Project) in the near future in order to daylight (i.e., bring aboveground) Willow Creek downstream from the Marsh, and to achieve other restoration enhancements within the Marsh.[3] As the Marsh is the only remaining salt marsh within the nearshore habitat zone of Watershed Resources Inventory Area (WRIA) 8 (the Lake Washington/Cedar/Sammamish Watershed), the Project is a high-priority for restoration (SRFB 2014, 2018).

The purpose of this document is to describe the development of the ecosystem services model used to help estimate the ecological impact of the Project. Several different types of ecosystem services models are available; however, the Habitat Equivalency Analysis (HEA) model was selected in this case due to its ability to evaluate habitat-based ecosystem service changes within a number of different habitat types, and because this model has been used within the Puget Sound Region for a number of estuarine habitat mitigation projects (NOAA 2013; CBNRT 2002).

The HEA model developed for the Project is based on the most up-to-date conceptual designs for the Project, identified as Preferred Alternative 6 in the *Draft Willow Creek Daylight Project, Expanded Marsh Concept Design and Hydraulic Modeling Report* (hereafter referred to as the Marsh Concept Design Report) (Shannon & Wilson 2019b). General information about the HEA model is provided in Section 2 of this document,

[3] The Project is also referred to as the Willow Creek Daylighting project in project planning documents (Shannon & Wilson 2015, 2019b).

and an explanation of the site-specific HEA model developed for the Project is provided in Section 3. The results of the Marsh HEA model analysis—which provide an estimate of the overall ecological benefit associated with the Project based on habitat functions—are specified in Section 4.

Section 5 provides recommendations for habitat features that could be incorporated into the final Project design, including species of plants that would be suitable for the new and enhanced riparian buffer zones to be created as part of the Project, and suggestions related to the placement of large woody debris (LWD), within both the new daylighted creek channel and the Marsh interior. This section also provides recommendations for post-construction monitoring that could be implemented in the future to help detect and quantify changes in ecosystem services and habitat quality resulting from implementation of the Project.

2 Habitat Equivalency Analysis Approach to Project Evaluation

The HEA model was developed by the National Oceanographic and Atmospheric Administration (NOAA) to assist with selecting and planning habitat compensation projects associated with natural resource damages (NRD). NRD compensation is required when it is understood that releases of environmental contaminants have likely caused loss or degradation of habitat. HEA model analyses are used to evaluate the potential impacts on and restoration potential of a range of habitat types, primarily estuaries and tidal wetlands, salmon streams, coral reefs, and seagrasses (NOAA 2000).

The HEA model requires several input parameters in order to calculate the ecological service losses of an event like an oil spill or the ecological service benefits of a restoration project. Under an NRD scenario, the model is used to calculate both the impacts of an injurious event (referred to as "injury," or a loss of natural resources) and the benefits of a compensatory restoration project (referred to as natural resources services "lift"), to ensure that the benefits of the latter will balance out (i.e., make up for) the impacts of the former. The HEA model in this document is used simply to estimate the ecological benefit associated with a restoration project. Therefore, only the following input parameters necessary for calculating the ecosystem services lift side of the equation are needed:

- The baseline condition and existing types and sizes (acreage) of habitats present within the restoration project footprint
- An estimate of the types of habitats that will be created/restored, and an estimate of the post-restoration sizes (acreage) of those habitats
- The relative habitat value associated with each habitat type
- The start and completion dates of on-site restoration activities
- The anticipated time it will take for the new/restored habitats to mature and become fully functional
- The anticipated lifespan of the restoration project
- A real discount rate (applied as in the science of economics) to translate future value into present-day value (this rate is estimated based on published literature and is typically set at 3%)

Habitat values can be thought of as scores or ratings for different habitat types based on their value to certain fish or wildlife species. They are relative values, ranging from 0.0 (or a number very near 0.0 [i.e., 0.1]) to 1.0. A value near 0.0 is assigned to habitat types that are considered to provide little or no viable habitat to a given species or suite of species; a value of 1.0 is assigned to habitat types that are considered to provide ideal habitat for a species or suite of species. This approach is based upon the Habitat Evaluation Procedures developed in the early 1980s by the US Fish and

Wildlife Service (USFWS) (Schamberger et al. 1982). Habitat values can be developed by considering the value of a certain habitat type to a single species (e.g., Chinook salmon), to a single species during a particular life stage (e.g., juvenile Chinook salmon), or to a suite of species (e.g., assemblages of birds with similar foraging behavior, such as surface-searching/shallow-probing shorebirds (NOAA and USFWS 2012)).

In an effort to make this report as easy to understand as possible, and to keep it focused on the Marsh Project, a detailed explanation of the HEA model is not included. However, an overview of HEA provided by NOAA (2000) is included as Appendix A for readers who wish to better understand the model and its underlying equations. Additional discussion of the input parameters developed specifically for the Project is provided in the following sections.

3 Edmonds Marsh Estuary Restoration Project HEA

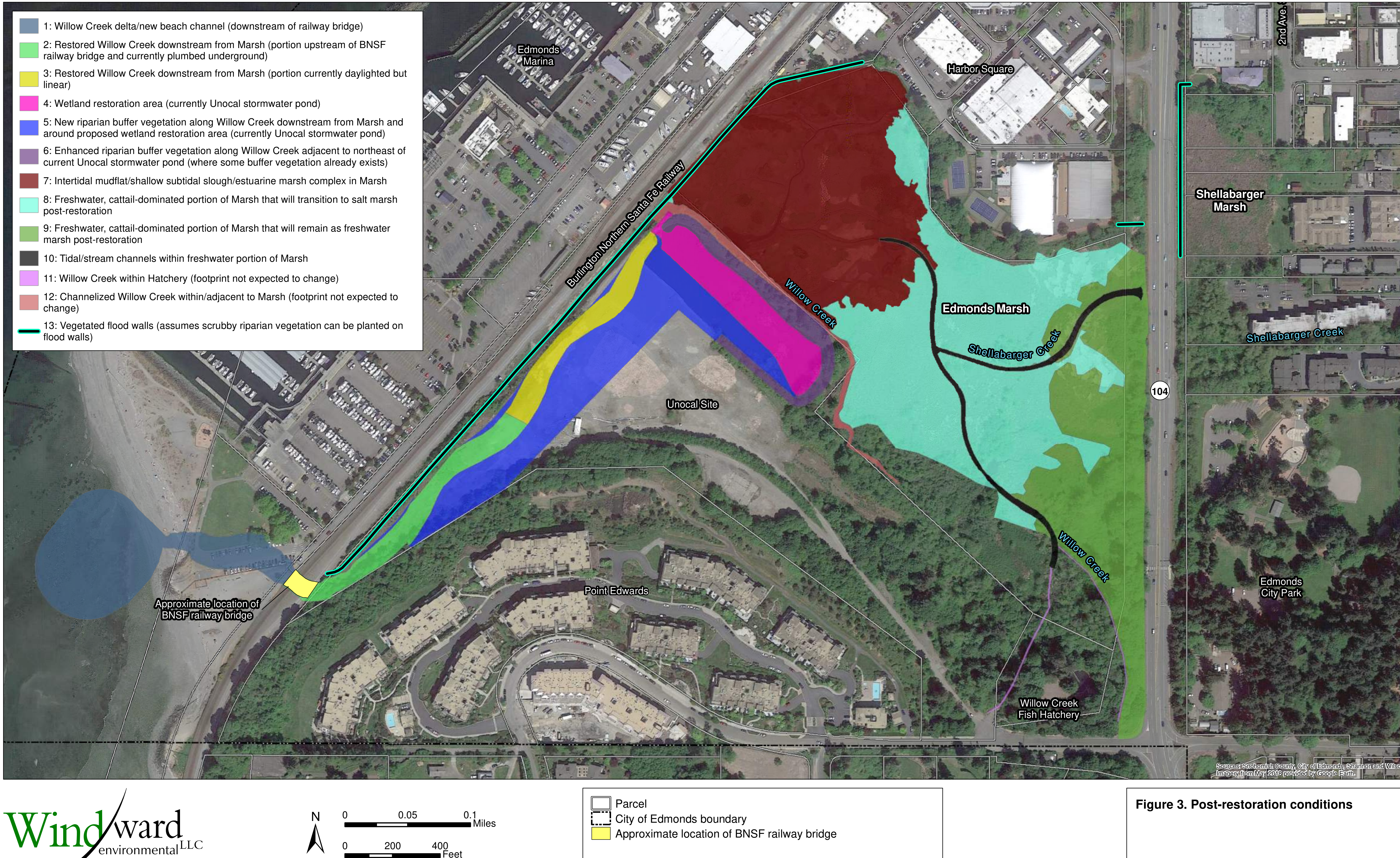
The Project will provide an array of enhancements to the ecological functions of the Marsh, its tributary creeks, and adjacent buffer areas. The HEA model helps quantify the benefits of the Project based on improved habitat functions. This section further explains how, based on the most recent conceptual design for the Project, the input parameters for a site-specific HEA model were developed.

3.1 Additional Description of the Project and its Anticipated Ecological Impacts

The City has conducted an evaluation of design alternatives for the alignment of a daylighted Willow Creek downstream from the Marsh, as well as other habitat features such as the excavation of tidal/stream channels within the Marsh. A draft report describing the conceptual design and hydraulic modeling for the Project was submitted to the City in March 2019 (Shannon & Wilson 2019b). The preferred alternative for the Project, identified in the report as Alternative 6, was used as the basis for developing the Marsh HEA model.[4]

Alternative 6 would create a sinuous, daylighted channel with a low-flow habitat channel, wetland bench, and LWD (Shannon & Wilson 2019b). The purpose of these features would be to maintain water depths and velocities that provide suitable conditions to allow fish passage under a variety of flow regimes, and to provide habitat complexity and cover. Additional discussion of the role of LWD in providing habitat is provided in Section 5.1. The new stream channel would be surrounded by a riparian buffer, which would average approximately 3 m (10 ft) in width on the northwest side of the stream channel and approximately 33.5 m (110 ft) in width on the southeast side of the stream channel (Figure 3). The riparian buffer would shade the new creek channel to help keep water temperatures cool and would contribute organic matter, such as fallen leaves and sticks; LWD, such as larger fallen branches and trees (eventually, as adjacent riparian vegetation grows, matures, and dies); and invertebrate prey, such as insects fallen from vegetation. The riparian buffer would also protect the stream channel from disturbance and allow for infiltration of stormwater. Additional habitat functions expected to be provided by riparian vegetation are discussed in Section 5.2.

[4] It is understood that the conceptual design for the Project will undergo future modifications as it is developed toward a final design. These modifications will be based upon additional design studies such as geomorphic assessments, feedback from the City and its community members, input from permitting and granting agencies, and coordination with adjacent land owners (Shannon & Wilson 2019b).



Parcel
City of Edmonds boundary
Approximate location of BNSF railway bridge

Note: Some post-restoration boundaries were delineated from external CAD and GIS drawings, data, and/or figures. These data should be considered approximate represenations.

Figure 3. Post-restoration conditions

Prepared by mikey, 4/8/2019; W:\Projects\Edmonds Marsh\Data\GIS\Maps and Analyses\HEA\Fig 3_7042_Post_restoration conditions.mxd

Alternative 6 would also restore tidal/stream channels within the eastern portion of the Marsh to allow both Shellabarger and Willow Creeks to flow within defined channels. It would convert a stormwater pond formerly used at the Unocal Site (Figure 1) into a restored wetland with a connection to Willow Creek on its northwest end. Alternative 6 would also include flood walls (i.e., earthen walls intended to help contain flood waters) on the northwest side of the Marsh and daylighted stream channel, along the west side of Shellabarger Marsh, and in the east corner of Harbor Square. The purpose of the flood berms would be to prevent flooding along the SR-104 and Burlington Northern Santa Fe (BNSF) rights-of-way during tidal storm surges and under high sea level conditions (Shannon & Wilson 2019b).

Daylighting Willow Creek and restoring natural tidal energy into and out of the Marsh would have numerous benefits. The most obvious direct benefit would be restoring access to the Marsh and its tributary creeks for migratory fish, particularly juvenile salmonids. Pocket marshes provide ideal rearing and foraging habitat for juvenile fish, including Chinook and chum (Beamer et al. 2006), and such marshes are very rare along this part of the Puget Sound shoreline. Restoring consistent sediment porewater salinities would be expected to benefit the benthic invertebrate community, a valuable source of prey for fish and birds. The composition and abundance of the benthic invertebrate community are linked to salinity (Sapiens 2014). It is very possible that dramatic fluctuations in sediment porewater salinities in the estuarine portion of the Marsh are stressing the benthic invertebrate community, contributing to the low diversity rating observed in 2017 (Shannon & Wilson 2019a).

Upon removal of downstream constrictions, the improved daily flushing of water into and out of the Marsh would be expected to allow the Marsh to fill and drain more completely with the incoming and outgoing tide. This will restore the export of fine-grained sediments and organic matter, which are currently retained in the Marsh, to the Puget Sound nearshore environment. In addition, dissolved oxygen (DO) concentrations in the Marsh interior—particularly at the northern end of the Marsh, where water quality monitoring has shown low DO (Edmonds Stream Team 2017; Shannon & Wilson 2019a)—would be expected to increase with increased water circulation and flushing. The estuarine marsh, mudflat, and tidal sloughs habitat footprints within the Marsh would also be expected to expand under conditions of unrestricted tidal and stream flows.[5] As the freshwater, cattail-dominated portion of the Marsh would be converted to salt marsh under restored conditions, plant diversity would be expected to increase, and small pools or ponds may form amongst the vegetation patches. Estuarine marsh, mudflat, and tidal slough habitats types are extremely valuable to juvenile salmonids and other native fish and bird species that depend upon nearshore environments (Fresh 2006; Eissinger 2007; Oring et al. 1983).

[5] For the purposes of this HEA model, it is assumed that the majority of the expansion of mudflat and tidal slough habitat will occur within the existing estuarine marsh footprint (Figure 2) and the excavated tidal/stream channel in the eastern portion of the Marsh (Figure 3).

All of these predicted changes are expected to increase the ability of the Marsh to provide suitable habitat for the animals that depend on it (from benthic invertebrates to fish and birds), as well as to provide enhanced ecological functions related to water quality and nutrient cycling and export.

The conceptual design for Alternative 6 will be further developed in future design stages (Shannon & Wilson 2019b), eventually moving toward a detailed design that can be used to obtain permits for and construct the project. Design elements to be further detailed during this process should include additional specifications for the channel shape and dimensions, planting plans for the new riparian buffer habitats, LWD quantities and installation methods, and possibly specifications for the placement of new streambed substrates like gravels and cobbles. Section 5 of this report provides recommendations for invasive species control, native plant selections, and LWD placement within both the new stream channel and the Marsh; these recommendations could be considered as the City moves from conceptual to final designs for the Project.

3.2 Evaluation of Habitat Type and Acreage Changes

Information regarding existing habitat types and acreages within the Marsh, as well as downstream from the Marsh in the area the daylighted Willow Creek channel will traverse, was available from a number of sources, including the Willow Creek daylighting feasibility studies (Shannon & Wilson 2015, 2019b), information collected to date as part of the Marsh baseline study (Windward 2018), and aerial photographs. These information sources were used (with geographic information system [GIS] software) to develop a map of current habitat conditions (Figure 2), and to estimate the acreages of both existing and post-restoration habitat types (Figure 3).

The conceptual design drawing for Alternative 6 as presented in the Marsh Concept Design Report (Shannon & Wilson 2019b) was used as the basis for delineating the habitat types and acreages expected to be created and restored as a result of the Project. In many cases, details of the post-restoration habitat types were clearly delineated in the Alternative 6 conceptual design drawings, such as: the sizes and locations of the daylighted creek channel and tidal/stream channel excavations within the Marsh, the footprint of the wetland restoration area that may be created in the location of the Unocal stormwater pond,[6] the enhanced riparian buffers along the new creek channel and restored wetland area, and the flood walls. In other cases, assumptions had to be made about what post-restoration habitat areas might look like. For example, the boundary between Marsh areas that will be dominated by salt-tolerant vegetation (i.e., salt marsh) and Marsh areas that will be dominated by freshwater vegetation (e.g., cattails) had to be estimated. This was accomplished using information about the range of surface elevations that would be expected to support

[6] Restoring the stormwater pond to wetland habitat is discussed as an optional element of the Project; however, it is included in the HEA model.

low- and high-marsh plants post-restoration (Shannon & Wilson 2019b) in combination with light detection and ranging (LiDAR) data for the Marsh. It should be emphasized that this was simply an estimate. The actual boundary between salt marsh and freshwater marsh will depend on a number of factors, such as the effectiveness of newly excavated stream/tidal channels in conveying saltwater to the eastern lobe of the Marsh, future sea levels, and possibly even an effort to control cattails (which can be salt tolerant (Beare and Zedler 1987)) and common reed (*Phragmites australis*) in order to allow salt marsh plants to colonize areas currently dominated by cattail stands. Additional information about cattail and common reed control options is provided in Section 5.3.

It is difficult to predict precisely how estuarine marsh vegetation patches and adjacent mudflat and tidal slough/channel networks will be distributed after restoration. Therefore, these three habitat types were considered as a single, connected habitat complex within the western portion of the Marsh (Figure 3) for the purpose of estimating the future size and habitat value of this habitat footprint. These habitat types are regarded as especially valuable when they occur adjacent to one another in a complex, because they can then provide enhanced ecological functions, such as the delivery of invertebrate prey from marsh vegetation to fish foraging in adjacent tidal sloughs (NOAA and USFWS 2012).

Although not explicitly discussed or delineated in the Marsh Concept Design Report (Shannon & Wilson 2019b), a newly developed stream delta where Willow Creek enters Puget Sound was included in the Marsh HEA model. The approximate size and configuration of the new stream delta were estimated by looking at aerial photographs of the delta areas of other small streams in the Puget Sound Region.

The HEA model developed for the Project also considered the existing Willow Creek channel that runs along the south side of the Marsh and through the Hatchery property. Although these portions of the creek are not expected to undergo active restoration as part of Alternative 6, they will see an increase in habitat value (as discussed further in Section 3.3) once downstream barriers to fish passage have been removed and they are again accessible to migratory fish. For this reason, acreages for these portions of the creek were estimated and included in the analysis.

Figure 3 presents the post-restoration habitat types, locations, and footprints, based on the analyses and assumptions described above. GIS was used to calculate the acreages of habitat type changes between existing and assumed future conditions. These acreages are presented in Table 2, which also describes the existing land cover/habitat types within the restoration Project footprint, as well as the associated post-restoration land cover/habitat types.

Table 2. Acreages for different habitat type changes associated with the Project

Habitat Type Change	Existing Land Cover/Habitat Type Designation[a]	Post-restoration Land Cover/Habitat Type Designation	Total Acreage for this Area
1: Willow Creek delta/new beach channel (downstream of railway bridge)	existing beach, intertidal/shallow subtidal shoal, and waterfront park	new Willow Creek beach channel and delta	2.90
2: Restored Willow Creek downstream from Marsh (portion upstream of BNSF railway bridge and currently plumbed underground)	creek running through an underground pipe system; some scrub-shrub and grass vegetation growing along railroad tracks	Willow Creek restored to above-ground, meandering channel with LWD, riparian buffer, etc.	1.10
3: Restored Willow Creek downstream from Marsh (portion currently daylighted but linear)[b]	a linear, channelized creek channel; hydrology affected by downstream drainage and tide gate infrastructure; currently, mostly contains paved or graveled upland areas with little to no riparian vegetation	Willow Creek restored to above-ground, meandering channel with LWD, riparian buffer, etc.	0.84
4: Wetland restoration area (currently Unocal stormwater pond)	currently a mostly open-water stormwater detention pond (small quantity of emergent or scrub-shrub vegetation visible within pond based on aerial photos)	pond restored to scrub-shrub and/or emergent vegetation wetland (assumes existing scrub-shrub and emergent vegetation patches will be expanded)	1.34
5: New riparian buffer vegetation along Willow Creek downstream from Marsh and around proposed wetland restoration area (currently Unocal stormwater pond)	paved or graveled area with small amount of presumably scrub-shrub vegetation (based on aerial photo review); a portion of the new riparian buffer area to be established along/within the southwest portion of the Unocal stormwater pond	new riparian buffer with dense plantings of native trees, shrubs, and groundcover species	3.37
6: Enhanced riparian buffer vegetation along Willow Creek adjacent to northeast of current Unocal stormwater pond (where some buffer vegetation already exists)	low-quality buffer vegetation (existing trees and shrubs, some native and some non-native)	enhanced riparian buffer with more dense, native plantings and more trees	0.90
7: Intertidal mudflat/shallow subtidal slough/estuarine marsh complex in Marsh	existing intertidal mudflat/shallow subtidal slough/estuarine marsh complex	enhanced intertidal mudflat/shallow subtidal slough/estuarine marsh complex	7.67

Habitat Type Change	Existing Land Cover/Habitat Type Designation[a]	Post-restoration Land Cover/Habitat Type Designation	Total Acreage for this Area
8: Freshwater, cattail-dominated portion of Marsh that will transition to salt marsh post-restoration	existing cattail-dominated marsh	restored salt marsh	8.64
9: Freshwater, cattail-dominated portion of Marsh that will remain as freshwater marsh post-restoration	existing cattail-dominated marsh	enhanced cattail-dominated marsh	5.41
10: Tidal/stream channels within freshwater portion of Marsh	cattail-dominated marsh vegetation where channels currently do not exist	tidal/stream channels within Marsh (channels expected to traverse both salt marsh and freshwater marsh areas)	0.60
11: Willow Creek within Hatchery (footprint not expected to change)[c]	Willow Creek within Hatchery: currently exists and is in relatively good condition; fish access restricted due to downstream blockages	Willow Creek within Hatchery; fish access restrictions removed	0.10
12: Channelized Willow Creek within/adjacent to Marsh (footprint not expected to change)	creek currently exists in relatively degraded condition (channelized, no LWD, thick and silty bottom substrates); fish cannot access due to downstream blockages	no change (in size or condition) as a result of daylighting project; will become accessible to salmonids once downstream fish passage barriers removed	0.41
13: Vegetated flood walls[d]	low-quality upland habitat	vegetated flood walls (vegetated flood walls expected to offer new areas for native scrub-shrub habitat, providing a new narrow band of scrub-shrub vegetation at the marsh edge)	1.00

[a] Existing land cover/habitat types within the vicinity of the planned daylighted creek channel, new wetland area (currently a stormwater pond), and associated riparian buffers have not been assessed directly due to access restrictions on the Unocal Site.

[b] The course of the existing daylighted creek channel is actually slightly north of the footprint for the proposed daylighted, meandering channel.

[c] The acreage of the creek channels within the Hatchery was estimated using the lengths of the channels and a width ranging from approximately 1 to 2 m (4 to 6 ft).

[d] It is not totally clear how large the flood walls will be or what types of habitat they will replace; for the purposes of this analysis, it is assumed that they will replace low-quality upland habitat and add a habitat enhancement by allowing additional buffer vegetation to be installed around the Marsh perimeter. The assumed acreage for the portion of the flood walls that could be vegetated (1 acre) is based on the cost estimate for Alternative 6b provided in the Marsh Concept Design Report (Shannon & Wilson 2019b), which indicates 1 acre of “side slope revegetation seeding and mulching” associated with the flood walls.

BNSF – Burlington Northern Santa Fe
Hatchery – Willow Creek Fish Hatchery
LWD – large woody debris
Marsh – Edmonds Marsh
Project – Edmonds Marsh Restoration Project (Willow Creek Daylighting)

3.3 DEVELOPMENT OF HABITAT VALUES

The habitat values (or scores) for the different habitat types discussed in Section 3.2 were developed by considering the specific habitat requirements of species known to use the Marsh and/or its tributary creeks in their current conditions, or that are expected to use the restored habitats after Project implementation. A number of fish, bird, and mammal species were selected for consideration when developing the site-specific habitat values. Table 3 lists these species, as well as the rationale for including each in the analysis. Table 3 also summarizes information on the specific habitat requirements, diets, and foraging styles of each species.

Table 3. Habitat requirements, diet and foraging information, and rationale for selection of specific species

Species	Rationale for Selection	Ecological Role (e.g., Forage Fish, Piscivorous Bird, Top Predator, Etc.)	General Habitat Requirements	Diet/Foraging Behavior
Juvenile Chinook salmon (*Oncorhynchus tshawytscha*)	Puget Sound Chinook are listed as threatened under the Endangered Species Act; a primary focus of the Project, it is one of the two salmon species that most heavily use nearshore habitat (along with chum salmon).	migratory juvenile fish	Rearing habitats require low gradient, shallow water with fine-grained substrates, low salinity, and low wave energy. Varying habitat features, including small tidal features with high connectivity to deeper habitats, increase the viability of juveniles. Pocket estuaries near natal deltas are used for feeding in the migrant fry stage (Fresh 2006). In the Skagit Bay and Whidbey Basin systems, wild migrant Chinook fry were found to prefer non-natal pocket estuaries to adjacent nearshore environments, and the availability of the former habitats led to higher survival and growth rates for the salmon in the later winter and spring (February through May) (Beamer et al. 2006). Pocket estuaries also support prey species of the Chinook salmon, including surf smelt.	Terrestrial insects (non-biting midges and other flies, beetles, aphids and other true bugs, plant lice, etc.), crustaceans (e.g., shrimp-like mysids), gammarid amphipods, copepods, and ostracods are all important prey resources for juvenile Chinook (Cordell et al. 2001; Woo et al. 2017; Miller and Simenstad 1997).
Coho salmon (*Onchorhynchus kisutch*)	This species is reared at the Hatchery. Small numbers are incidentally released to the creek, and Willow Creek could provide suitable rearing habitat, as coho spend at least 1 year rearing in streams (Fresh 2006). Prior to mid-2000s, larger numbers of coho were released to Upper Willow Creek from the Hatchery, with 20–40 adults returning to the creek annually to spawn (Shannon & Wilson 2015).	migratory juvenile fish	Coho generally use the deepest water in pools and LWD for cover; cover seems to be more important in winter than in summer for juveniles (Wydoski and Whitney 2003). At a DO level of < 5 mg/L, fry have impacted hatching success; reduced swimming speeds have been noted at DO levels of < 7 mg/L at 10 to 20°C (Hassler 1987).	Coho in streams feed primarily on insects (Diptera larvae, pupae, and adults, mayflies, stoneflies), worms, fish eggs, spiders, and fish (Wydoski and Whitney 2003). In estuarine habitats, flies, aphids, mysid shrimp, and gammarid amphipods have been shown to comprise a large proportion of juvenile coho diets (Miller and Simenstad 1997).
Chum salmon (*Oncorhynchus keta*)	This is one of the two salmon species that most heavily uses nearshore habitat (along with Chinook salmon). Adult chum were occasionally observed in Willow Creek in the past, but none have been observed in several years (Shannon & Wilson 2015).	migratory juvenile fish	Juvenile chum salmon often remain in the nearshore environment and in brackish waters for a number of months (Love 2011). In a study of fish use of pocket estuaries conducted in north Skagit County and the Whidbey Basin, juvenile chum salmon were 1 of the 6 most commonly captured fish species (Beamer et al. 2006). Chum salmon often spawn in short coastal streams and intertidal areas (Hale et al. 1985). Several studies have shown that in-stream areas where groundwater upwells through the gravel substrate are preferred locations for redds.	The chum diet includes small fishes and fish larvae, squids, crustaceans (e.g., amphipods, mysid shrimps, and copepods), worms, and terrestrial insects (Love 2011).
Three-spined stickleback (*Gasterosteus aculeatus*)	This species is currently present in Willow Creek and its habitat requirements are consistent with the current conditions being provided by Willow Creek.	small, schooling forage fish	Three-spined sticklebacks are weak swimmers displaced by high flow, generally associated with aquatic vegetation, and found close to the bottoms of streams. They are abundant in the slow, brackish water of shallow sloughs and estuaries (Wydoski and Whitney 2003). The species tolerates a range of salinities, and there are marine, anadromous, and freshwater populations (Love 2011). In a study of fish use of pocket estuaries conducted in north Skagit County and the Whidbey Basin, three-spined stickleback were 1 of the 6 most commonly captured fish species (Beamer et al. 2006).	A generalist feeder (visual predator), the three-spined stickleback has a diet primarily of small crustaceans (e.g., amphipods, mysid shrimps, copepods), insect larvae, snails, worms, terrestrial insects, and fish eggs (Wydoski and Whitney 2003; Love 2011).
Pacific sand lance (*Ammodytes hexapterus*)	This is one of the three most common forage fish species in Puget Sound and is representative of other nearshore forage fish; it would be expected to use new stream delta habitat created when Willow Creek is daylighted.	small, schooling forage fish	Pacific sand lance use shallow nearshore areas and are associated with fine gravel and sandy substrates. They spawn in autumn in the high intertidal zones of sand and gravel beaches; their spawning sites are scattered throughout Puget Sound (Penttila 2007). The species burrows into the top layer of sand/gravel substrates in the nearshore and low intertidal zones at night (likely to avoid predation) and when dormant (winter) (Penttila 2007; USFS 1999). They use both estuarine and fully marine environments. They are an important prey species for salmon and other fish and a large number of bird species.	Feeding by Pacific sand lance occurs in the water column; occasionally epibenthic invertebrates are eaten. Their diet consists of marine zooplankton, primarily copepods, but changes with age.
Spotted sandpiper (*Actitis macularius*)	This species is a common shorebird and representative of other shorebirds; it was observed breeding in Edmonds Marsh in the summer of 2018.	invertivorous bird	Spotted sandpiper feed along the sandy or muddy edges of water bodies and require semi-open vegetation with high invertebrate biomass (Oring et al. 1983). They breed in open habitats along the margins of water bodies (Oring and Lank 1986) but also amongst grasses, mosses, shrubs, and even logs within forested habitat (Ehrlich et al. 1988).	Adult flying insects are main component of the spotted sandpiper diet; smaller proportions include crustaceans, leeches, molluscs, small fish, and carrion (Oring et al. 1983).

Species	Rationale for Selection	Ecological Role (e.g., Forage Fish, Piscivorous Bird, Top Predator, Etc.)	General Habitat Requirements	Diet/Foraging Behavior
Killdeer (*Charadrius vociferus*)	This species is a year-round, common resident in the mudflat areas of Edmonds Marsh; it is representative of other shorebirds and plovers.	invertivorous bird	Killdeer use open areas, such as mudflats, short grass meadows, wetland lagoons, and reservoirs. They are also found in human-modified habitat such as agricultural and athletic fields, golf courses, or graveled lots/rooftops (Jackson and Jackson 2000). Nests are placed in open, mostly unvegetated areas with soft substrates (Ehrlich et al. 1988).	Killdeer eat terrestrial invertebrates, worms, grasshoppers, beetles, and snails and forage in open flats with no cover or in shallow water (Jackson and Jackson 2000).
Song sparrow (*Melospiza melodia*)	This species is a year-round, common resident of the Marsh observed in both estuarine and freshwater marsh habitats as well as the buffer zones; it is representative of other songbirds that use scrub-shrub habitat near water.	invertivorous bird	Habitat types used by song sparrows vary greatly, but most subspecies occupy and nest in areas consisting of shrubs growing on moist ground along streams, sloughs, marshes, or coastlines (Ehrlich et al. 1988; Arcese et al. 2002). The species is often found within edge habitat (e.g., edges of forests, lakes, streams, etc.) (The Cornell Lab of Ornithology 2017b).	The song sparrow diet changes seasonally from primarily seeds, fruits, and invertebrates in the non-breeding season to primarily insects and small invertebrates during breeding season. Feeding occurs through a variety of capture techniques (Arcese et al. 2002).
Marsh wren (*Cistothorus palustris*)	This species is a year-round, common resident of the vegetated emergent areas of the Marsh; it also breeds within the Marsh.	invertivorous bird	The marsh wren uses cover and nesting habitat provided by wetland plants such as cattails, bulrushes, cordgrasses, sedges, etc., and avoids abundant woody vegetation (Gutzwiller and Anderson 1987).	The marsh wren preys upon insects and spiders taken from vegetation and the marsh floor and also catches flies. Common insect prey include the orders Coleoptera (beetles), Diptera (flies), Hemipteran (true bugs) and Odanta (grasshoppers and crickets).
Great blue heron (*Ardea Herodias*)	This species is regularly observed resting and foraging in the Marsh year-round. It is a wading bird dependent upon a complex of nearshore habitat types.	top predator	Great blue herons rely on nearshore habitats, and saltwater and freshwater marshes are important foraging grounds throughout the year (Eissinger 2007). Inland marshes, streams, and riparian forests also provide shelter and roosting areas. Estuarine habitats are used year-round for foraging, loafing, staging, and dispersal of young. Breeding colonies are located within mature nearshore forests, where trees are large and stout enough to support the nests herons build from large sticks. Breeding sites are also selected for their proximity to foraging grounds, preferably eelgrass meadows, and protection from human disturbance.	The great blue heron's diet consists of fish, invertebrates, small mammals, and occasionally amphibians and reptiles (Eissinger 2007). Small mammals such as voles are particularly important prey items in the winter and for juvenile herons (which are not yet efficient at fishing). Three-spined stickleback is a targeted prey item, particularly during the breeding season. Great blue herons will forage from pieces of LWD and boulders during high tide.
Bald eagle (*Haliaeetus leucocephalus*)	Bald eagles currently hunt and roost within the Marsh; a nesting pair has been reported near the Point Edwards condominiums. Juvenile bald eagles are often observed within the Marsh and are representative of other aerial hunting birds.	top predator	Bald eagles prefer large, open trees near water. Eagles need perch trees that are stout enough to support their weight and are isolated from human disturbance (WDFD 2001).	Bald eagles are opportunistic feeders that obtain prey through active hunting, carrion feeding, or piracy (stealing prey from other animals). Their diet varies based on local prey sources available. The bald eagle will capture live fish swimming near the water surface or in shallow water; in the winter, waterfowl and shorebirds are important food sources (EPA 1993). Mammals such as rabbits and squirrels are also eaten.
Mallard (*Anas platyrhynchos*)	This species is a year-round, common resident of the Marsh and is often seen dabbling in the Marsh when it is inundated.	omnivorous forage bird	Mallards use marshes, forested wetlands, grain fields, ponds, rivers, lakes, bays, and city parks. They may occur in any kind of aquatic habitat but favor freshwater in all seasons; they are only sparingly found on coastal waters, mainly in winter and in sheltered bays and estuaries (Kaufman 2019).	Mallards forage in nearshore environments and graze on land. They are omnivorous, with a diet composed of mostly plant material (seeds, stems, roots of sedges, grasses, pondweeds, waste grain), they also consume insects, crustaceans, mollusks, earthworms, and small fish.Young mallard ducklings consume mostly aquatic insects (Kaufman 2019).
Belted kingfisher	This species has been observed near the daylighted portion of Willow Creek and the Unocal stormwater pond; it likely forages for three-spined stickleback present within the creek and is representative of other fish-eating birds.	carnivorous forage bird	Belted kingfisher prefer calm waters where prey is easily visible (i.e., streams, rivers, lakes, and estuaries) (Kelly et al. 2009). They hunt from perches along the edges of streams, estuaries, and other water bodies (The Cornell Lab of Ornithology 2017a). Kingfisher can occupy a variety of aquatic habitats, preferably with sufficient riffle area to forage, but have specific nesting requirements. Vertical banks are important for kingfishers to create nesting burrows (Brooks and Davis 1987).	Belted kingfisher prey on fish in shallow water and generally consume a wide variety of fish (although one study noted that belted kingfisher heavily focused on three-spined stickleback). Kingfisher also prey on crayfish (Kelly et al. 2009).
Columbian black-tailed deer (*Odocoileus hemionus columbianus*) – subspecies of mule deer	This species is frequently observed in trail camera photos from the Hatchery; it has been directly observed browsing along Willow Creek within the Hatchery.	browsing/grazing mammal	Columbian black-tailed deer use wooded areas for browsing and cover/shelter; they also use edge habitats and feed in more open areas at night. A diversity of habitats/seral forest stages in close association with one another is important to provide the necessary cover and foraging habitat for Columbian black-tailed deer (Innes 2013; Larrison 1976; Quinn 1997). Habitat areas 1 to 5 acres in size containing low shrubs and small trees 0.6 to 1.8 m (2 to 6 ft) high, gradual slopes, and approximately 50% canopy cover, and in close proximity to water, provide ideal fawning areas (Innes 2013).	Columbian black-tailed deer browse year-round upon a variety of woody plants, including western red cedar, salmonberry, willows, and thimbleberry, and also graze upon ferns, mosses, forbs, and grasses during the growing season; some species of lichens and mushrooms are also eaten (Innes 2013; USDA 1971).
Coyote (*Canis latrans*)	This species is frequently observed in trail camera photos from the Hatchery and tracks are often seen within the mudflat areas of the Marsh; coyote have also been directly observed in the Marsh.	carnivorous and carrion-eating mammal; highly adaptable	In urbanized areas, coyotes are closely associated with patches of secondary growth forest that remain in riparian areas and parks (Quinn 1997); they establish dens under rock outcroppings or large boulders, or as burrows in earthen banks (Larrison 1976).	A coyote's diet consists of a variety of prey items, including small rodents (e.g., moles, voles), squirrels, rabbits, birds, and deer; they also eat fruit (primarily apples and cherries in Western Washington) (Quinn 1997; Urban Coyote Research Project 2019; Gehrt 2007).

DO – dissolved oxygen Hatchery – Willow Creek Fish Hatchery LWD – large woody debris Marsh – Edmonds Marsh Project – Edmonds Marsh Restoration Project (Willow Creek Daylighting)

Using the information in Table 3, the ability of each habitat type to meet the needs of the selected species was determined, allowing the derivation of numerical habitat values. Habitat values were developed for current conditions and existing habitat types, as well as for anticipated future conditions of post-restoration habitat types (Table 4). When a certain habitat type was considered to be unsuitable for a given species, a habitat value of 0.1 was assigned. This reasonably low value reflects the low suitability of the habitat and has been used to indicate degraded habitat conditions in other regional HEA models (NOAA and USFWS 2012). A habitat value of 0.1 is preferable to a value of 0.0, which would complicate running the mathematical HEA equations. Table 4 provides detailed discussion of the rationale behind each habitat value assignment. The scarcity of nearshore pocket marsh habitat—which is rare in the Puget Sound Region, particularly between Seattle and Everett—was taken into account when assigning habitat values. In order to provide a single habitat value for each existing habitat type and post-restoration habitat type, the individual habitat values developed for each species were averaged to generate a single habitat value for each habitat type that could be plugged into the HEA model.

Table 4. Derivation of habitat values

Species Associated with Habitat Type	Current Habitat Value	Notes/Assumptions Related to Current Habitat Value	Post-restoration Habitat Value	Notes/Assumptions Related to Post-restoration Habitat Value
1: Willow Creek delta/new beach channel (downstream of railway bridge)				
Juvenile Chinook salmon	0.25	Juvenile Chinook may inhabit the intertidal and shallow subtidal zones in this area as they move up and down the Puget Sound shoreline, but as the new beach channel/ delta areas do not yet exist, they cannot be used by Chinook salmon.	0.75	The new delta and beach channel will allow for connectivity to the Marsh area, and will also likely provide additional foraging habitat, particularly if existing algae beds expand or eelgrass beds become established, as eelgrass and algae support salmonid prey species.
Pacific sand lance	0.5	Existing beach in this area may provide spawning and hibernating habitat for Pacific sand lance; however, the Willow Creek delta does not yet exist, as the creek discharges via an offshore, submerged pipe, so delta habitat cannot be used by sand lance.	0.75	The new beach channel and associated delta will likely increase the delivery of food resources for sand lance that may be using the beach habitat.
Coho salmon (possibly juveniles and adults entering Willow Creek to spawn)	0.25	Coho may inhabit the intertidal and shallow subtidal zones in this area as they move up and down the Puget Sound shoreline, but as the new beach channel/ delta areas do not yet exist, they cannot be used by coho salmon.	0.75	The new delta and beach channel will allow for connectivity to the Marsh area, and will also likely provide additional foraging habitat, particularly if existing algae beds expand or eelgrass beds become established, as eelgrass and algae support salmonid prey species.
Chum salmon (possibly juveniles and spawning adults)	0.25	Chum may inhabit the intertidal and shallow subtidal zones in this area as they move up and down the Puget Sound shoreline, but as the new beach channel/ delta areas do not yet exist, they cannot be used by chinook salmon	0.75	The new delta and beach channel will allow for connectivity to the Marsh area, and will also likely provide additional foraging habitat, particularly if existing algae beds expand or eelgrass beds become established, as eelgrass and algae support salmonid prey species.
Great blue heron	0.5	While the new beach channel/delta area does not yet exist and cannot be used by great blue heron, there is a large, shallow shoal in the intertidal and shallow subtidal zone in this area; it is likely that great blue heron forage in this area currently.	0.75	Lowland stream estuaries/deltas provide important foraging habitat for great blue heron, and it is assumed that foraging opportunities here will improve as sediment deposits from the creek help to build up new delta habitat and as fish move through the stream delta.
2: Restored Willow Creek downstream from Marsh (portion upstream of railway bridge and currently plumbed underground)				
Juvenile Chinook salmon	0.1	No salmonids have been documented entering the creek since the mid-2000s. It is understood that salmonids cannot currently access the creek from Puget Sound due to downstream blockages from drainage infrastructure (submerged outfall, pipes, and tide gate).	1.0	Once this area is restored, meanders, LWD, and naturally forming pools will provide habitat for juvenile Chinook to rest, feed, and move through, and the entire pocket estuary system will become accessible to juvenile Chinook.
Chum salmon (possibly juveniles and spawning adults)	0.1	No salmonids have been documented entering the creek since the mid-2000s. It is understood that salmonids cannot currently access the creek from Puget Sound due to downstream blockages from drainage infrastructure (submerged outfall, pipes, and tide gate).	1.0	The newly daylighted creek area will provide access to the Marsh area, as well as its own cover and foraging habitat. Chum tend to spend more time in nearshore estuarine environments than do other salmonid species and are more likely to spawn in short coastal streams and intertidal areas.
Three-spined stickleback	0.1	Although stickleback may be present in the creek, they likely only pass through the underground section.	0.75	The newly daylighted creek will provide cover and foraging habitat for stickleback and is likely to support the aquatic vegetation with which they are generally associated.
Coho salmon (possibly juveniles and adults entering Willow Creek to spawn)	0.1	No salmonids have been documented entering the creek since the mid-2000s. It is understood that salmonids cannot currently access the creek from Puget Sound due to downstream blockages from drainage infrastructure (submerged outfall, pipes, and tide gate). It is also not expected that coho released from the Hatchery would use this portion of the creek, since it is underground.	1.0	Coho generally use the deepest water in pools and LWD for cover. As this area is restored, suitable stream habitat with LWD, pools, overhanging vegetation, and meanders will become available, as will prey resources.
3: Restored Willow Creek downstream from Marsh (portion currently daylighted but linear)[a]				
Juvenile Chinook salmon	0.1	No salmonids have been documented entering the creek since the mid-2000s. It is understood that salmonids cannot currently access the creek from Puget Sound due to downstream blockages from drainage infrastructure (submerged outfall, pipes, and tide gate).	1.0	Once this area is restored, meanders, LWD, and naturally forming pools will provide habitat for juvenile Chinook to rest, feed, and move through, and the entire pocket estuary system will become accessible to juvenile Chinook.
Coho salmon (possibly juveniles and adults entering Willow Creek to spawn)	0.1	No salmonids have been documented entering the creek from Puget Sound since the mid-2000s, and it is not expected that coho salmon released from the Hatchery would be able to reach this portion of the creek due to upstream blockages (dense cattail marsh without a defined creek channel passage).	1.0	Coho generally use the deepest water in pools and debris for cover. As this area is restored, suitable stream habitat with LWD, pools, overhanging vegetation, and meanders will become available, as will prey resources.

Species Associated with Habitat Type	Current Habitat Value	Notes/Assumptions Related to Current Habitat Value	Post-restoration Habitat Value	Notes/Assumptions Related to Post-restoration Habitat Value
Chum salmon (possibly juveniles and spawning adults)	0.1	No salmonids have been documented entering the creek since the mid-2000s. It is understood that salmonids cannot currently access the creek from Puget Sound due to downstream blockages from drainage infrastructure (submerged outfall, pipes, and tide gate).	1.0	The newly daylighted creek channel downstream will provide access to this portion of Willow Creek, and habitat improvements including creek meanders, LWD, and riparian vegetation will make this high-quality habitat for chum. Chum tend to spend more time in nearshore estuarine environments than do other salmonid species and are more likely to spawn in short coastal streams and intertidal areas.
Three-spined stickleback	0.75	Large numbers of stickleback have been observed in this portion of the creek under current conditions; this area provides relatively slow-moving water (preferred by stickleback) due to downstream constrictions on water flow (submerged outfall, pipes, culverts, pipes and tide gate).	0.5	After Willow Creek has been daylighted and downstream constrictions on natural tidal and stream flow have been removed, it is anticipated that water velocities in this portion of the creek will increase compared to current conditions, making this portion of the creek slightly less suitable for stickleback. In addition, with the influx of salmonids and other fish from Puget Sound, it is expected that stickleback will experience increased competition and predation.
4: Wetland restoration area (currently the Unocal stormwater pond)				
Juvenile Chinook salmon	0.1	It is assumed that fish cannot currently access this area and that current conditions in the stormwater pond would provide little to no suitable habitat.	0.5	As a restored wetland, it is assumed that at least portions of this area (likely those nearest the connection to Willow Creek) will maintain water depths suitable for fish access, at least during high tide, and that this area will provide suitable resting and foraging habitat for juvenile Chinook.
Three-spined stickleback	0.1	It is assumed that fish cannot currently access this area and that current conditions in the stormwater pond would provide little to no suitable habitat.	0.75	Stickleback prefer low-velocity water flows and are often found in shallow sloughs and estuaries and in association with aquatic vegetation. It is expected that the restored wetland will create suitable conditions for stickleback, particularly in those areas nearest the connection to Willow Creek, where it is expected that water depths will allow fish access, at least during high tide.
Coho salmon (assumes juveniles most likely to use the wetland area)	0.1	It is assumed that fish cannot currently access this area and that current conditions in the stormwater pond would provide little to no suitable habitat.	0.5	As a restored wetland, it is assumed that this area will provide suitable resting and foraging habitat for juvenile coho, and that at least portions of the wetland (likely those areas nearest the connection to Willow Creek) will maintain water depths suitable for fish access, at least during high tide.
Chum salmon (assumes juveniles most likely to use the wetland area)	0.1	It is assumed that fish cannot currently access this area and that current conditions in the stormwater pond would provide little to no suitable habitat.	0.5	As a restored wetland, it is assumed that this area will provide suitable resting and foraging habitat for chum, and that at least portions of the wetland (likely those areas nearest the connection to Willow Creek) will maintain water depths suitable for fish access, at least during high tide.
Spotted sandpiper	0.25	Although a small amount of potential habitat exists in this area due to the presence of the stormwater pond and its adjacent "shoreline," the current presence of spotted sandpiper cannot be confirmed due to access restrictions in this area.	0.5	This area will likely provide some shoreline and shallow feeding habitat for spotted sandpiper, but it is anticipated that dense, scrub-shrub riparian buffer vegetation will be established along the wetland margins, making this area too densely vegetated for ideal shorebird habitat.
Song sparrow	0.2	Based on aerial photo review, the majority of the stormwater pond is unvegetated (e.g., primarily open water); therefore, it is not expected to provide suitable habitat for song sparrows, although they may make limited use of the few scrub-shrub plants growing within the more elevated ground areas within the pond.	1.0	Assuming that the stormwater pond is restored to a scrub-shrub and emergent vegetation wetland, it will provide ideal habitat for song sparrows.
Killdeer	0.25	As killdeer are often found in lagoons and human-modified habitats, this area has the potential to provide habitat for killdeer; however, the current presence of killdeer cannot be confirmed due to access restrictions in this area, and any habitat currently provided is likely of low quality.	0.50	This area will likely provide some shoreline and semi-open habitat for killdeer, but it is anticipated that dense, scrub-shrub riparian buffer vegetation will be established along the wetland margins, making this area too densely vegetated for ideal killdeer habitat.
Belted kingfisher	0.1	It is assumed that there are currently no fish or other suitable food sources available to belted kingfisher in the stormwater pond; however, belted kingfisher use or non-use of this area has not been confirmed due to access restrictions in this area.	0.8	Restoring the stormwater pond to a wetland that is accessible to fish (via the connection to Willow Creek on its northwest side) and surrounded by riparian buffer vegetation is expected to provide highly suitable belted kingfisher perching/foraging habitat; the overall suitability of the habitat will depend upon the depth of the water and the numbers of fish that are able to access the wetland.
Great blue heron	0.1	It is assumed that there are currently no fish or other suitable food sources available to great blue heron in the stormwater pond; however, great blue heron use or non-use of this area has not been confirmed due to access restrictions in this area.	0.75	Restoring the stormwater pond to a wetland that is accessible to fish (via the connection to Willow Creek on its northwest side) and surrounded by riparian buffer vegetation is expected to provide highly suitable foraging habitat for herons; heron prey, including fish, rodents, and possibly amphibians and reptiles, are expected to be present post-restoration.

Species Associated with Habitat Type	Current Habitat Value	Notes/Assumptions Related to Current Habitat Value	Post-restoration Habitat Value	Notes/Assumptions Related to Post-restoration Habitat Value
Mallard	0.75	Mallard have often been observed flying between this area and the Marsh. Based on aerial photo review, the stormwater pond currently provides suitable open-water conditions for mallard.	0.5	The suitability of this habitat area for mallard may decline post-restoration, if the open-water, pond-like conditions are replaced by scrub-shrub and/or emergent marsh habitat; however, the wetland will likely still provide suitable mallard habitat, depending on the depth of water maintained post-restoration.
5: New riparian buffer vegetation along Willow Creek downstream from Marsh and around proposed wetland restoration area (currently the Unocal stormwater pond)				
Bald eagle	0.1	Currently, this area does not contain trees large enough to support bald eagle roosting.	0.50	Eventually, this area is expected to produce trees large enough to support perching/hunting eagles; the riparian vegetation cover will also likely increase habitat for eagles' prey species.
Song sparrow	0.25	Currently, only a portion of this area contains woody vegetation and it is of low quality (a narrow, sparsely vegetated band with invasive species); much of this area is also not currently adjacent to water (i.e., where Willow Creek runs underground).	1.0	After restoration, this area is expected to provide dense, native scrub-shrub vegetation adjacent to a water source (daylighted Willow Creek), which should provide ideal habitat for song sparrows
Belted kingfisher	0.1	Currently, only a portion of this area contains woody vegetation and it is of low quality (a narrow, sparsely vegetated band with invasive species); the adjacent pond is not expected to contain fish; therefore, this area currently provides low-quality habitat for belted kingfisher.	0.8	Post-restoration, it is anticipated that this area will provide new perching/hunting habitat for belted kingfishers adjacent to a fish-bearing creek and wetland.
Columbian black-tailed deer	0.1	Currently, only a portion of this area contains woody vegetation and it is of low quality (a narrow, sparsely vegetated band with invasive species); the area is assumed to currently provide very little browse for deer.	0.5	After restoration, this area is expected to provide dense, native scrub-shrub vegetation adjacent to a water source (daylighted Willow Creek), which should provide increased browse and water access for deer. It is anticipated that the nearby railroad right-of-way may affect how deer use at least the northern portion of this area.
Coyote	0.25	It is assumed that this area may be used by coyote for traversing or resting, and that there may occasionally be coyote prey items (e.g., voles) present in this area; however, as there is little vegetation here currently, it likely does not support a very dense population of coyote prey species, which tend to occupy densely vegetated areas that provide them with cover and food.	0.75	Post-restoration, this area will provide a dense riparian buffer that is adjacent to wetland habitat and the daylighted Willow Creek stream channel, which should provide highly suitable habitat for both coyotes and their preferred prey items (e.g., voles and rabbits); installation of fruiting plants such as native cherry and apple trees in the buffer would also provide food sources for coyote.
6: Enhanced riparian buffer vegetation along Willow Creek adjacent to northeast of current stormwater pond (where some buffer vegetation already exists)				
Bald eagle	0.5	Vegetation in this area is relatively sparse, but bald eagles have been observed perching in the larger trees growing here.	0.75	An enhanced native, woody vegetation community is expected to provide more trees appropriate for eagles to perch upon and hunt from; denser vegetation would also discourage human access/disturbance in this area.
Song sparrow	0.5	This area currently provides suitable song sparrow habitat, and song sparrows are observed here commonly; however, existing vegetation is of moderate quality (somewhat sparse and containing non-native species).	1.0	After restoration, this area is expected to provide an enhanced native, woody vegetation community adjacent to water sources (Willow Creek and a wetland restoration area), which should provide ideal habitat for song sparrows.
Belted kingfisher	0.5	This area currently provides suitable perching/hunting habitat (it is adjacent to Willow Creek, which supports three-spined stickleback, a common prey fish for belted kingfisher), and belted kingfisher have been observed in the vicinity; however, existing vegetation is of only moderate density and quality.	0.8	Enhanced buffer vegetation will provide better perching/ hunting habitat; Willow Creek daylighting will allow more fish (prey items for belted kingfisher) to access this area.
Columbian black-tailed deer	0.25	Vegetation in this area is relatively sparse and contains a mix of native and non-native species.	0.75	After restoration, this area is expected to provide an enhanced native, woody vegetation community that will include preferred browse items for Columbia black-tailed deer, such as western red cedar, salmonberry, willows, thimbleberry, and ferns. It will also provide access to water (Willow Creek) and be adjacent to the more open habitats of the Marsh and wetland restoration area, providing the habitat mix and edge habitats that deer prefer.
Coyote	0.5	This area provides some riparian vegetation currently and likely supports populations of coyote prey items such as voles and other rodents.	0.75	Enhanced riparian vegetation will create enhanced shelter and food sources for coyote and their prey species; if fruiting plants such as native cherry and apple trees are installed in the buffer, they will also provide food sources for coyote.
7: Intertidal mudflat/shallow subtidal slough/estuarine marsh habitat complex in Marsh				
Juvenile Chinook salmon	0.1	No salmonids have been documented entering Willow Creek or the Marsh since the mid-2000s due to downstream blockages to fish passage.	1.0	Daylighting Willow Creek will provide salmonids access to the sloughs and mudflats in the Marsh; such habitat types within pocket estuaries have been shown to provide highly suitable rearing and foraging habitat for juvenile Chinook salmon.

Species Associated with Habitat Type	Current Habitat Value	Notes/Assumptions Related to Current Habitat Value	Post-restoration Habitat Value	Notes/Assumptions Related to Post-restoration Habitat Value
Three-spined stickleback	0.5	Sticklebacks currently present in Willow Creek may use this area.	1.0	Stickleback were one of the species most commonly observed in pocket estuaries in a study conducted within the Skagit Bay and Whidbey Island; while stickleback currently have physical access to and may likely use this area, habitat conditions for stickleback should be more amenable once a more naturally functioning pocket estuary has been restored.
Coho salmon (assumes juveniles most likely to use the habitat complex)	0.1	No salmonids have been documented entering Willow Creek or the Marsh since the mid-2000s due to downstream blockages to fish passage.	0.75	Daylighting Willow Creek will provide salmonids access to the sloughs and mudflats in the Marsh; coho salmon would possibly make use of this area for foraging and rearing, although coho are more likely to rear in streams.
Chum salmon (assumes juveniles most likely to use the habitat complex)	0.1	No salmonids have been documented entering Willow Creek or the Marsh since the mid-2000s due to downstream blockages to fish passage.	1.0	Daylighting Willow Creek will provide salmonids access to the sloughs and mudflats in the Marsh; such habitat types within pocket estuaries have been shown to provide highly suitable rearing and foraging habitat for chum salmon.
Killdeer	0.8	Killdeer thrive in mudflats, as food is abundant in these areas and foraging occurs in areas of no cover or shallow water; killdeer are frequently observed in this habitat area under its current conditions.	0.9	This area will continue to provide good habitat for killdeer roosting and foraging; mudflat habitat will likely expand, providing more of the habitat type most used by killdeer.
Spotted sandpiper	0.75	This area currently provides foraging habitat for spotted sandpiper, and a breeding spotted sandpiper was observed in the summer of 2018.	0.9	This area will continue to meet the needs of spotted sandpiper; the density and diversity of benthic invertebrate prey resources and amount of edge habitat between mudflat and fringing marsh habitat are expected to increase after the restoration project has been implemented.
Great blue heron	0.5	Great blue heron roost and forage in marshes and are commonly observed within the Marsh; however, it is likely that few fish (with the possible exception of some stickleback) are present within the sloughs under current conditions. Other prey items such as rodents likely are available.	0.8	After restoration, it is anticipated that this area will support an increased fish population, increasing herons' food opportunities; additionally, the overall extent of mudflat and slough habitat will likely expand, providing additional estuarine habitat for heron use.
Belted kingfisher	0.25	While this area may provide foraging opportunities for kingfisher (assuming some of the stickleback in Willow Creek migrate into the tidal sloughs during high tides/storm flow events), prey opportunities are considered to be limited due to fish access restrictions for anadromous species.	0.75	After restoration, fish presence is expected to increase in these habitat areas; therefore, more prey will be available for belted kingfisher.
Mallard	0.75	Mallards are observed year-round in the Marsh; it is believed that the habitat provided by the slough complex is best for mallard when freshwater inflows are high and tidal flows are restricted (in fall and winter), due to the species' preference for fresh water.	0.5	It is expected that mallards will continue to use the Marsh post-restoration, but habitat suitability may decline in the fall and winter months due to year-round tidal flows, which will raise the salinity of water in the sloughs compared to current conditions.
Marsh wren	1.0	Marsh wren have been observed within existing stands of dense vegetation; vegetation preferred by marsh wrens, such as bulrushes and cattail, are present within this portion of the Marsh; marsh wren prey species, such as spiders and flies, have been commonly observed in the Marsh and in invertebrate samples collected from the Marsh.	1.0	The quality of marsh wren habitat and prey base is not expected to change significantly as a result of the Project; while there may be shifts in the type of wetland vegetation present, the overall quantity of wetland plants appropriate for marsh wren use is expected to remain relatively similar.
Coyote	1.0	Coyote have frequently been observed (seen directly or evidenced by tracks, scat, and feather piles likely left by coyote after preying upon waterfowl) using this portion of the Marsh, which is understood to provide highly suitable coyote habitat (cover, resting areas, and a variety of prey items) in its current condition. The Marsh also provides a drinking water source for wildlife.	1.0	This portion of the Marsh already provides highly suitable coyote habitat that is not expected to change as a result of the Project.
8: Freshwater, cattail-dominated portion of Marsh (portion expected to transition to salt marsh post-restoration)				
Marsh wren	1.0	The marsh wrens regularly observed within this portion of the Marsh and its associated cattails (a wetland plant that provides ideal cover and nesting habitat for the marsh wren) are currently predominant there. Marsh wrens use cattail down to line their nests, and invertebrate fallout trap data collected from the Marsh have shown that areas dominated by cattail produce a large quantity of flies, a prey item of the marsh wren.	1.0	This portion of the Marsh is expected to provide high-quality marsh wren habitat and prey base; although there will be shifts in the type of wetland vegetation present, the overall quantity of wetland plants appropriate for marsh wren use is expected to remain relatively static.
Song sparrow	0.5	Much of this area currently lacks access to stream banks; however, it does provide scrub-shrub habitat in the form of "islands" of willow and alder growing within predominantly cattail stands.	0.3	The value of this area for song sparrows is expected to be reduced, because this species prefers scrub-shrub habitat; replacing cattails and other scrubby vegetation (i.e., willows and alders) currently growing within the freshwater portion of the Marsh with salt marsh vegetation will likely result in a plant community dominated by more grass-like, lower-growing forms of vegetation.

Species Associated with Habitat Type	Current Habitat Value	Notes/Assumptions Related to Current Habitat Value	Post-restoration Habitat Value	Notes/Assumptions Related to Post-restoration Habitat Value
Spotted sandpiper	0.1	Spotted sandpiper prefer semi-open habitats for foraging and breeding; the very tall, dense growth within the cattail-dominated portion of the Marsh is not expected to provide suitable habitat for spotted sandpiper.	0.75	As cattails begin to be replaced by more salt-tolerant plant species, a greater diversity of vegetation (including more grass-like forms of vegetation), a patchier distribution of vegetation growth, and interspersed small ponds/pools, this area is expected to provide the semi-open habitat preferred by spotted sandpiper.
Killdeer	0.1	This area currently does not provide suitable killdeer habitat because of the tall, dense growth of cattails and other scrub-shrub vegetation and a lack of short vegetation and open areas.	0.75	As cattails begin to be replaced by more salt-tolerant plant species, a greater diversity of vegetation (including more grass-like forms of vegetation), a patchier distribution of vegetation growth, and interspersed small ponds/pools, this area is expected to provide more suitable habitat for killdeer, which commonly use fields as well as mudflat areas.
Great blue heron	0.5	Great blue herons have been observed in the cattail-dominated portion of the Marsh, but usually near the Willow Creek stream channel; it is expected that the dense cattail stands farther from the creek channel are less valuable to great blue herons than is estuarine marsh habitat.	0.75	Great blue herons are much more commonly observed roosting and foraging in the estuarine portion of the Marsh; therefore, transitioning from cattail-dominated marsh to a more diverse estuarine marsh is considered to provide increased habitat value for this species. In addition, the new tidal/stream channels in this area will provide access to additional prey resources (e.g., fish).
Coyote	1.0	Coyote have been directly observed traversing the freshwater, cattail-dominated portion of the Marsh, an area that provides the dense vegetative cover preferred by coyote prey species such as voles. The Marsh also provides a drinking water source for wildlife. It is likely that coyotes use this portion of the Marsh just as much as they use the estuarine/mudflat portion, but it is more difficult to observe them here due to the dense cattail cover.	1.0	Coyote have been observed using both the freshwater, cattail-dominated portion of the Marsh and the estuarine/mudflat portion. It is expected that both of these habitat types provide highly suitable coyote habitat (cover, resting areas, water sources, and a variety of prey items) and that overall, the value of the Marsh for coyotes will not change significantly as a result of the Project.
9: Freshwater, cattail-dominated portion of Marsh (portion that will remain freshwater marsh post-restoration)[b]				
Marsh wren	1.0	Marsh wren are regularly observed within this portion of the Marsh and its associated cattails (a wetland plant that provides ideal cover and nesting habitat for the marsh wren). Marsh wrens use cattail down to line their nests, and invertebrate fallout trap data collected from the Marsh have shown that areas dominated by cattail produce a large quantity of flies, a prey item of the marsh wren	1.0	This area is expected to remain as high-quality habitat for marsh wrens, as they use both estuarine and freshwater marsh habitats; however, cattail may be replaced by other marsh vegetation after the Project has been implemented and there is enhanced tidal water flow in this portion of the Marsh.
Song sparrow	0.5	Much of this area currently lacks access to stream banks; while there are some "islands" of willow and alder growing within this portion of the Marsh, much of it is dominated by cattail stands.	0.75	Song sparrow will benefit from the new creek channels as they prefer habitat in proximity to water; however, vegetation in this area likely to remain primarily emergent and not scrub-shrub
Coyote	1.0	Coyote have been directly observed traversing the freshwater, cattail-dominated portion of the Marsh, an area that provides the dense vegetative cover preferred by coyote prey species such as voles. The Marsh also provides a drinking water source for wildlife. It is likely that coyotes use this portion of the Marsh just as much as they use the estuarine/mudflat portion, but it is more difficult to observe them here due to the dense cattail cover.	1.0	This portion of the Marsh already provides highly suitable coyote habitat that is not expected to change as a result of the Project.
10: Tidal/stream channels within freshwater Marsh				
Three-spined stickleback	0.1	Currently, there are no defined tidal/stream channels within the freshwater portion of the Marsh; therefore, fish are not able to access the area.	0.5	Once the new tidal/stream channels have been created in this area, fish will have access to this area; it is expected that stickleback may migrate into this portion of the Marsh. Water velocities in the channels may be too high for stickleback at times, particularly when storm flows are being conveyed through the channels.
Coho salmon (possibly juveniles and adults entering Willow Creek to spawn)	0.1	Currently, there are no defined tidal/stream channels within the freshwater portion of the Marsh; therefore, fish are not able to access the area.	0.75	Once the new tidal/stream channels have been created in this area, fish will have access to this area; it is expected that coho may migrate to or from the Hatchery via these channels.
Spotted sandpiper	0.1	Currently, there are no defined tidal/stream channels within the freshwater portion of the Marsh; therefore, this habitat type is not available for spotted sandpipers.	0.75	Tidal channels will increase the shoreline areas that spotted sandpipers could access for foraging and cover; vegetation in this area is expected to remain too dense to provide suitable nesting habitat.
Great blue heron	0.1	Currently, there are no defined tidal/stream channels within the freshwater portion of the Marsh; therefore, this habitat type is not available for herons.	0.75	Tidal channels will increase fish access to this area and therefore foraging grounds and food sources for great blue heron.
Mallard	0.1	Currently, there are no defined tidal/stream channels within the freshwater portion of the Marsh; therefore, this habitat type is not available for ducks.	1.0	This area would be expected to provide highly suitable foraging and nesting habitat for mallards once access is provided via the tidal/stream channels.

Species Associated with Habitat Type	Current Habitat Value	Notes/Assumptions Related to Current Habitat Value	Post-restoration Habitat Value	Notes/Assumptions Related to Post-restoration Habitat Value
11: Willow Creek within Hatchery				
Coho salmon (possibly juveniles and adults entering Willow Creek to spawn)	0.25	Some coho have been incidentally released in this area from the Hatchery. Willow Creek provides rearing and foraging habitat but currently no viable route to Puget Sound.	0.75	Increased connectivity to the lower Marsh and Puget Sound would allow coho rearing in this area to continue their life cycle by migrating downstream to the estuary and saltwater. Adult coho returning to this portion of the creek may also find suitable spawning habitat.
Three-spined stickleback	0.1	It is unknown whether stickleback are currently present in this portion of Willow Creek; they may not be able to access it due to lack of stream connection from the lower creek to the portion of the creek on the Hatchery property	0.5	Water velocities in this area may limit habitat suitability for stickleback, particularly during inflows from storm events; however, LWD, aquatic vegetation, and other habitat structure in this part of the creek would be expected to provide some suitable habitat for stickleback.
Belted kingfisher	0.2	Currently, few fish are expected to be present in this area (e.g., coho released from the hatchery); therefore, it provides little prey for belted kingfisher.	0.5	After restoration, fish access to this area is expected to increase; therefore, more prey will be available for belted kingfisher. However, as this bird prefers to hunt in calm water, the creek in this area may never provide ideal belted kingfisher habitat.
12: Channelized Willow Creek within/adjacent to Marsh				
Juvenile Chinook salmon	0.1	No salmonids have been documented entering Willow Creek or the Marsh since the mid-2000s due to downstream blockages to fish passage.	0.75	Post-restoration, juvenile Chinook salmon will have access to this area; restoration within the riparian buffer of this portion of the creek will enhance habitat by providing overhanging vegetation, shade, and contributions to prey resources. However, habitat conditions will not be ideal, as the creek is channelized and lacks LWD.
Three-spined stickleback	0.5	Although fish survey data are not available for this portion of Willow Creek, it is assumed that stickleback are present; stream velocities may be greater here than in the lower creek, making the habitat slightly less suitable for stickleback.	0.65	Access and habitat conditions for stickleback are expected to remain relatively static in this part of the creek, although adjacent riparian vegetation enhancements will likely improve habitat conditions.
Chum salmon (possibly juveniles and adults entering Willow Creek to spawn)	0.1	No salmonids have been documented entering Willow Creek or the Marsh since the mid-2000s due to downstream blockages to fish passage.	0.75	Post-restoration, chum salmon will have access to this area; restoration within the riparian buffer of this portion of the creek will enhance habitat by providing overhanging vegetation, shade, and contributions to prey resources. Habitat conditions will not be ideal, as the creek is channelized and lacks LWD, but chum could rear and spawn in this portion of the creek if substrates were suitable.
Coho salmon (possibly juveniles and adults entering Willow Creek to spawn)	0.1	No salmonids have been documented entering Willow Creek or the Marsh since the mid-2000s due to downstream blockages to fish passage.	0.75	Post-restoration, coho salmon will have access to this area; restoration within the riparian buffer of this portion of the creek will enhance habitat by providing overhanging vegetation, shade, and contributions to prey resources. However, habitat conditions will not be ideal, as the creek is channelized and lacks LWD.
13: Vegetated flood walls (assume scrubby riparian vegetation can be planted on flood walls)[c]				
Belted kingfisher	0.1	Currently, this feature does not exist.	0.5	It is anticipated that native scrub-shrub vegetation installed on the flood walls will provide hunting/perching habitat for belted kingfishers; however, these areas are expected to be relatively narrow compared to other vegetated buffers and riparian forests. In addition, maintenance of the flood walls and their proximity to rail and road rights-of-way may reduce their habitat value.
Song sparrow	0.1	Currently, this feature does not exist.	0.5	Native scrub-shrub vegetation installed on the flood walls will provide cover, perching habitat, and possibly nesting habitat for song sparrows; however, these areas are expected to be relatively narrow compared to other vegetated buffers and riparian forests. In addition, maintenance of the flood walls and their proximity to rail and road rights-of-way may reduce their habitat value. The flood walls are also expected to provide prey items in the form of seeds and invertebrates.
Columbian black-tailed deer	0.1	Currently, this feature does not exist.	0.5	Native scrub-shrub vegetation installed on the flood walls will provide browse for deer; however, use of these areas by deer may be limited by the areas' proximity to road and railroad rights-of-way.

[a] This area contains a sparse, narrow band of vegetation that is dominated by non-native plants, based on a review of photos provided as Appendix A of the final feasibility study for the Project (Shannon & Wilson 2015). Access restrictions currently in place within this portion of the site make direct observations impossible.

[b] This Marsh area will be enhanced by excavating tidal/stream channels, allowing better access for fish and wading birds.

[c] It is assumed that installation of the vegetated flood walls will not cause any loss of wetland habitat, or that any wetland impacts will be mitigated on-site, resulting in no net loss of wetland habitat within the Marsh system.

Hatchery – Willow Creek Fish Hatchery LWD – large woody debris Project – Edmonds Marsh Restoration Project (Willow Creek Daylighting)

3.4 Temporal Inputs

Temporal inputs—construction dates, maturation rates, and project lifespan—are another important component of the HEA model. The year of restoration defines the start date for calculating functional ecosystem services lift. Maturation rates help determine how quickly the restored habitat areas will reach their full potential in terms of providing habitat functions, and the assumed project lifespan helps determine an end date for the calculation. For the Marsh HEA model, the year 2020 was used as the presumed construction year, and a lifespan of 80 years was chosen because hydraulic modeling using assumptions about sea level conditions in the year 2100 has been conducted and shows Marsh habitats remaining intact (Shannon & Wilson 2019b). The maturation rates developed for the HEA model are explained in Table 5.

Table 5. Maturation rates for different habitat type changes

Habitat Type Change	Expected Maturation Rate	Basis
1: Willow Creek delta/new beach channel (downstream of railway bridge)	• initial habitat function bump to 91.6% of anticipated full function 4 years post-restoration • full function 8 years post-restoration	• Lower Duwamish River and Commencement Bay NRDA HEA models • maturation rates for intertidal habitat
2: Restored Willow Creek channel downstream from Marsh (portion upstream of BNSF railway bridge and currently plumbed underground)	• initial habitat function bump to 60% of anticipated full function 1 year post-restoration • full function 8 years post-restoration	• initial bump to 60% 1 year post-restoration assumed because fish access will be open immediately and installed LWD will be available • full function 8 years post-restoration based on other models developed for stream channels and time to full function for the associated riparian buffer
3: Restored Willow Creek downstream from Marsh (portion currently daylighted but linear)	• initial habitat function bump 1 year post-restoration • full function 8 years post-restoration	• initial bump to of 60% 1 year post-restoration assumed because fish access will be open immediately and installed LWD will be available • full function 8 years post-restoration based on other models developed for stream channels and time to full function for the associated riparian buffer
4: Wetland restoration area (currently Unocal stormwater pond)	• initial habitat function bump to 82.5% of anticipated full function 4 years post-restoration • additional habitat function bump to 93.6% of anticipated full function 8 years post-restoration • full function at 15 years post-restoration	• Lower Duwamish River and Commencement Bay NRDA HEA models • maturation rates for estuarine marsh
5: New riparian buffer vegetation along Willow Creek downstream from Marsh and around proposed wetland restoration area (currently Unocal stormwater pond)	• initial habitat function bump to 50% of anticipated full function 4 years post-restoration • full function 8 years post-restoration	• Lower Duwamish River and Commencement Bay NRDA HEA models • maturation rates for vegetated buffer
6: Enhanced riparian buffer vegetation along Willow Creek adjacent to northeast of current Unocal stormwater pond (where some buffer vegetation already exists)	full function 4 years post-restoration	• Lower Duwamish River and Commencement Bay NRDA HEA models (4-year time period for vegetated buffer to achieve initial bump) • assumes that, with existing vegetation in this area, full function can be achieved within 4 years once invasive species are controlled and additional native plants are installed; canopy already exists

Habitat Type Change	Expected Maturation Rate	Basis
7: Intertidal mudflat/shallow subtidal slough/estuarine marsh complex in Marsh interior	• initial habitat function bump to 82.5% of anticipated full function 4 years post-restoration • full function 6 years post-restoration	• Lower Duwamish River and Commencement Bay NRDA HEA models (initial bump of 82.5% 4 years post-restoration for intertidal, shallow subtidal channel, and estuarine marsh habitats) • Lower Duwamish River and Commencement Bay NRDA HEA models (6-year time period to achieve full function): average between time periods for achieving initial and second bumps (4 and 8 years, respectively) for intertidal, shallow subtidal channel, and estuarine marsh habitats, since mudflat, subtidal/intertidal slough, and estuarine marsh habitats are already present in this area and just need time to mature under restored, full-tidal regime)
8: Freshwater, cattail-dominated portion of Marsh that will transition to salt marsh post-restoration	• initial habitat function bump to 82.5% of anticipated full function 4 years post-restoration • additional habitat function bump to 93.6% of anticipated full function 8 years post-restoration • full function 15 years post-restoration	• Lower Duwamish River and Commencement Bay NRDA HEA models (15 years for estuarine marsh to achieve full function) • assumes 15 years needed to suppress cattail and replace with native salt-tolerant marsh plants
9: Freshwater, cattail-dominated portion of Marsh that will remain as freshwater marsh post-restoration	full function 1 year post-restoration	• only acreage expected to change, not habitat type/quality • assumes 1 year needed to recover from habitat disturbances caused when stream/tidal channels excavated in this portion of the Marsh
10: Tidal/stream channels in freshwater portion of Marsh	full function 1 year post-restoration	• main function of channels to provide access for fish and other wildlife in this portion of Marsh; access provided once channels created • necessary to monitor channels to ensure they stay open and maintain their habitat function as time goes on
11: Willow Creek within Hatchery	full function 1 year post-restoration	only fish accessibility due to downstream actions expected to change, not habitat type, quality, or footprint
12: Channelized Willow Creek within/adjacent to Marsh	full function 1 year to post-restoration	only fish accessibility due to downstream actions expected to change, not habitat type, quality or footprint
13: Vegetated flood walls (assumes scrubby riparian vegetation can be planted on flood walls)	initial habitat function bump to 50% of full function 4 years post-restoration; reach full function 8 years post-restoration	maturation rates for vegetated buffer habitat type from Lower Duwamish River and Commencement Bay NRDA HEA models

BNSF – Burlington Northern Santa Fe
Hatchery – Willow Creek Fish Hatchery
HEA – Habitat Equivalency Analysis
LWD – large woody debris
Marsh – Edmonds Marsh
NRDA – natural resource damages assessment

3.5 DISCOUNT RATE

The standard 3% discount rate used in all regional HEA models was also used for the Marsh HEA model. The value assigned to a restoration project is the sum of discounted services provided over the project's lifespan, translated to the present time at a 3% discount rate. The resulting unit of the HEA model output is a discounted service-acre year (dSAY). This unit reflects the ecological services delivered by each acre of a certain habitat type over the period of a year, with services in future years discounted to present-day value. The dSAYs are calculated by HEA as an accumulation of services over the estimated lifespan of the Project.

4 Model Results

The HEA model was run using R (R Core Team 2018), which is code-based software with statistics and data visualization capabilities. The software includes many built-in functions, and users can create their own algorithms to analyze data in specific and complex ways. Windward Environmental LLC generated the necessary R code to run the HEA model and to visualize the outcome of the analysis. The model input parameters described in Section 3 were entered into the R code, and the model was run to calculate the value of the Project in dSAYs.

The dSAY unit is a generalized measure of services that combines different services provided by different habitat types into a single value. In order to standardize the habitat values generated by each area when calculating a generic dSAY value, each area is multiplied by a conversion factor. In the Puget Sound Region, estuarine marsh is often used as the "gold standard" habitat type to which others are compared. For example, the Lower Duwamish River HEA model uses a conversion factor of 0.5 to translate a riparian buffer habitat value (called "vegetated buffer" in the model) to an estuarine marsh habitat value.

For the Project, the services provided by each habitat type were multiplied by a value relative the services provided by estuarine marsh. Therefore, the 0.5 conversion factor from the Lower Duwamish River model was applied to convert the dSAY values of Area 5 (new riparian vegetation buffer), Area 6 (enhanced riparian buffer vegetation), and Area 13 (vegetated flood walls) to their estuarine marsh equivalents. A conversion factor of 0.8 was applied to Area 9 (the freshwater, cattail-dominated portion of the Marsh) and Area 12 (channelized Willow Creek within/adjacent to Marsh), as these habitat types were considered to be slightly less valuable to fish and wildlife species than was estuarine marsh. The other habitat types (Areas 1 through 4, 8, 10, and 11) were all considered to provide the highest level of function for fish and wildlife, consistent with the value of estuarine marsh, so no conversion factors were applied to the dSAY totals for these areas. For each habitat type, the dSAY value—which is based on all of the HEA parameters described in Section 3 (e.g., Tables 2 through 5) and converted, as applicable—is provided in Table 6.

Table 6. Model results for each habitat type

Habitat Type	Total dSAYs	dSAYs/ acre
1: Willow Creek delta/new beach channel (downstream of railway bridge)	31	11
2: Restored Willow Creek downstream from Marsh (portion upstream of BNSF railway bridge and currently plumbed underground)	25	23
3: Restored Willow Creek downstream from Marsh (portion currently daylighted but linear)	14	17
4: Wetland restoration area (currently Unocal stormwater pond)	15	11
5: New riparian buffer vegetation along Willow Creek downstream from Marsh and around proposed wetland restoration area (currently Unocal stormwater pond)	28	8

Habitat Type	Total dSAYs	dSAYs/ acre
6: Enhanced riparian buffer vegetation along Willow Creek adjacent to northeast of current Unocal stormwater pond (where some buffer vegetation already exists)	4.4	5
7: Intertidal mudflat/shallow subtidal slough/estuarine marsh complex in Marsh	68	9
8: Freshwater, cattail-dominated portion of Marsh that will transition to salt marsh post-restoration	49	6
9: Freshwater, cattail-dominated portion of Marsh that will remain as freshwater marsh post-restoration	11	2.0
10: Tidal/stream channels within freshwater portion of Marsh	11	19
11: Willow Creek within Hatchery (footprint not expected to change)	1.2	12
12: Channelized Willow Creek within/adjacent to Marsh (footprint not expected to change)	5.0	12
13: Vegetated flood walls (assumes scrubby riparian vegetation can be planted on flood walls)	5.1	5
Total	**268**	**7.8**

BNSF – Burlington Northern Santa Fe
dSAY – discounted service-acre year
Marsh – Edmonds Marsh

To provide context for the results shown in Table 6, the dSAY/acre values of NRD projects that have been conducted in Oregon and Washington were reviewed to the extent possible; however, this type of information is often hard to find. In general, a range of 13 to 16 dSAYs/acre is typical for NRD projects. While the total result for the Project of 7.8 dSAYs/acre (Table 6) may make it appear that it would be worth less than other projects, this is not the case. Compensatory NRD restoration projects usually occur at sites that provide little to no habitat value in their existing conditions.[7] In contrast, the Marsh is a remnant estuarine pocket wetland that provides valuable habitat to birds, some fish species, and other wildlife in its current condition (Table 4). Therefore, the smaller dSAY/acre result for the Project reflects the higher value of the Marsh under current conditions compared to other restoration sites, rather than a less valuable restoration project.

To better evaluate the actual net gain in ecosystem services that would be provided by the Project, the future value of the Marsh (in dSAYs/acre) was estimated assuming no change in current conditions. At its current level of habitat function (i.e., unchanged baseline conditions), the Marsh[8] could provide approximately 429 dSAYs (13 dSAYs/acre) over the next 80 years. However, given the current pressures on the Marsh in the absence of restoration, it is unlikely that current conditions would continue under this scenario. Under the proposed Project, the Marsh and its tributary creeks would be expected to provide an additional 267 dSAYs (7.8 dSAYs/acre), which is a 62% improvement in total dSAYs over current conditions. Together, the estimated current value of the Marsh and the value added by the Project would provide an overall value of 698 dSAYs (20 dSAYs/acre).

The expectation that current conditions in the Marsh will continue in the absence of the Project is optimistic. If the Project is not implemented, the freshwater, cattail-dominated portion of the Marsh is likely to continue to expand westward; as fine-grained sediments continue to build up in the Marsh system, the patches of willow, alder, and other scrub-shrub vegetation intermixed with the cattail will likely expand also. This could result in the transition of the pocket estuary into a predominantly scrub-shrub marsh, or even upland habitat. Therefore, implementing the Project will both protect the current level of services provided by the Marsh and enhance those services.

[7] NRD projects often occur at old industrial sites, many of which are contaminated, or at degraded agricultural sites that have been diked and drained, and that no longer support wetland habitat or native plants.

[8] These dSAY values are those associated with the existing Marsh and the portions of the Unocal Site and Marina Beach Park that will be incorporated into the system by the Project (i.e., all areas listed in Table 2).

5 Recommendations for Habitat Features and Post-restoration Monitoring

The purpose of this section is to provide initial recommendations for habitat features that could be incorporated into the Project design and monitoring methods that could be employed post-restoration to track changes in habitat conditions and fish and wildlife use of the Marsh. Section 5.1 provides general guidelines for LWD installation quantities and methods within both the new daylighted creek channel and the Marsh; however, engineering expertise will be required to determine the appropriate numbers and types of LWD that should be installed, as well as the appropriate anchoring techniques, particularly since the Project is located within a developed urban area. Section 5.2 provides recommendations related to planting in the new and enhanced riparian buffer areas and vegetated flood walls. Section 5.3 provides recommendations related to the control of cattail and phragmites vegetation patches; controlling such vegetation may be required in order for the restored Marsh to reach its full ecological potential. Finally, Section 5.4 discusses post-construction monitoring that could be implemented after restoration to help detect and quantify changes in ecosystem services and habitat quality resulting from implementation of the Project.

5.1 Recommendations for LWD Installation

LWD provides complex habitat features for invertebrates and wildlife; it can also serve as "nurse logs," providing habitat for native plants (Sheldon et al. 2005). Invertebrates feed off the detritus produced by LWD, and many species live within or beneath pieces of LWD (Sheldon et al. 2005; Brennan et al. 2009). Avian species utilize LWD for roosting, nesting, and foraging (Sheldon et al. 2005; Bottorff 2009). LWD also provides refuge and denning habitat for many native mammal species (Bottorff 2009), and the species richness (diversity) of small mammals in the wetlands of the Puget Sound Region has been found to be closely related to the quantity of LWD within the buffer areas (Sheldon et al. 2005). LWD provides important habitat structure and cover for fish and contributes to the formation of pool habitat in streams (Sheldon et al. 2005; Christensen 2000; Gurnell et al. 2002). LWD also provides organic matter inputs to streams and other water bodies (Christensen 2000). The majority of the literature surrounding LWD is focused on riverine settings; less is known about LWD in estuarine settings. However, the presence of LWD in both settings provides important habitat functions and should be considered when planning restoration projects. The following subsections discuss general recommendations for the placement of LWD within the new daylighted Willow Creek stream channel (Section 5.1.1) and the Marsh (Section 5.1.2). These recommendations could be considered during development of the final design for the Project; however, engineering expertise will be required to determine the actual quantities, types, and placement methods appropriate for the Project.

5.1.1 In-stream LWD

Recommendations for the quantity and sizes of LWD appropriate for installation in restored stream channels in the Puget Sound Region depend upon the size (bankfull width) of the stream (Montgomery et al. 2003). After the Project is completed, the average width of the daylighted/restored Willow Creek channel downstream from the Marsh is expected to be approximately 17 m (55 ft).[9] For a stream channel of this size, a density of approximately 63 pieces of LWD for every 100 m (328 ft) of channel length (totaling approximately 99 m^3 of LWD by volume) would result in high-quality in-stream habitat based on the metric of LWD quantity. Regional recommendations for LWD size and quantity also specify that at least four “key pieces” of LWD—LWD at least 9 m^3 in volume for a stream the size of Willow Creek—should be included in the total of 63 pieces. Key pieces of LWD are larger than other pieces and contribute to pool formation and accumulations of additional pieces of LWD (e.g., logjams) more so than smaller pieces.

The National Marine Fisheries Service (NMFS) Pacific Coast Salmon Plan also contains recommendations for LWD quantities in order for a stream to achieve “properly functioning conditions” (Montgomery et al. 2003). The NMFS criteria recommend a minimum of 80 pieces of LWD per mile of stream channel. The Washington State Department of Natural Resources (WDNR 2013) gives minimum diameter recommendations for LWD. Based on these guidelines, LWD in the daylighted Willow Creek channel should be greater than approximately 66 cm (26 in.) in diameter.

When LWD is installed as part of a restoration project, it can be anchored naturally (e.g., by embedding a portion of the LWD piece into the adjacent stream bank) or with cables and anchors. Anchoring LWD helps to hold the wood in place, ensuring that it stays within the restored stream channel reach and does not migrate downstream. Migration of LWD out of restoration sites can cause problems such as erosion, flooding, and damage to downstream infrastructure such as bridges and culverts.

In channels wider than 30 m (100 ft), LWD pieces with rootwads are considered to be especially important for stabilization (Montgomery et al. 2003). Fischenich and Morrow (2000) offer recommendations for installing and anchoring LWD in stream habitat enhancement projects, such as trimming limbs before anchoring. The authors state that when feasible, it is desirable to anchor LWD by partially burying it. Other anchoring techniques include using a live tree stump (i.e., partially cut the trunk of a live tree so that it falls into the stream); using a tree stump or live tree as an anchor (i.e., wrap a cable around the trunk, taking care not to place the cable directly on the bark of a live tree); or using rebar, a weighted anchor (e.g., concrete-filled container), a buried anchor (e.g., partially buried reinforced anchor), or a commercially manufactured anchor. The LWD should be anchored in at least two points, and the distance from the anchor to the LWD should be as small as possible. Cable is

[9] Channel width is expected to range from approximately 35 (11 m) to 70 ft (21 m).

preferred, but chain or rope can also be used to attach the LWD to the anchor. The cable should be as straight as possible (i.e., should not follow the curve of a bank). If the cable does extend over the top of a bank, a ditch in which to place the cable may be necessary.

5.1.2 Large woody debris in the Marsh interior

Within estuarine marshes, LWD is thought to provide inputs of detritus that help support the estuarine food web, shelter (from both high-velocity currents and predators), and egg attachment sites for fish, and to serve as habitat islands that vegetation, particularly shrubs, can colonize, thereby increasing species and habitat diversity (Hood 2007). Various bird species also use LWD for roosting and as hunting platforms, particularly during high tides (Eissinger 2007; Hood 2007). As in riparian environments, LWD in estuarine marshes can help hold soils in place, reducing erosion and scour as tides flow in and out.

In a study of tidal marshes in the Skagit River estuary, the average quantity of LWD present covered approximately 2.6% of the marsh surface (Hood 2007). LWD at least 80 cm (approximately 31 in.) in diameter at its midpoint was shown to be particularly susceptible to being colonized by woody shrub species (Hood 2007). Due to anthropogenic changes such as diking rivers and removing lowland forests, estuarine marshes are often no longer able to naturally recruit as much LWD as they did historically. Therefore, the restoration of LWD within estuarine marshes, as well as within stream corridors and rivers, is recommended for consideration.

It is recommended that the City look for ways to incorporate the placement of LWD within the Marsh during implementation of the Project, as there are currently very few pieces of LWD in the estuarine portion of the Marsh. There appear to be more pieces of LWD within the cattail-dominated portion of the Marsh near its forested edges; however, it is difficult to visually assess the quantity and quality of that LWD due to the dense cattail stands and other growth. It would be preferable to place LWD within the Marsh using equipment that is either staged in upland areas or already accessing the Marsh for other construction purposes. Such an approach would prevent compaction of Marsh soils beyond the extent necessary to complete the earthwork associated with the daylighting and tidal/stream channel excavations. Anchoring should be considered to ensure that installed LWD remains in place and stable, and that it does not cause problems with any of the built infrastructure surrounding the Marsh.

5.2 Recommendations for Plantings in New Riparian Buffers and on Flood Berms

The recommendations in this section provide some initial ideas for selecting native plants that would be suitable for installation within the new and enhanced wetland/riparian buffers included in the Project design, as well as on the flood walls (Figure 3). As the Project moves toward final design, a detailed planting plan for these areas will be developed. Table 7 presents information on the growth requirements for a number of native tree, shrub, and groundcover species that would be suitable for planting within these areas, as many of them are adapted to saline environments and a variety of soil types, hydrologic conditions, and sunlight tolerances. Table 7 also provides information about some of the ecological functions provided by these species.

Table 7. Native species appropriate for new and enhanced riparian buffer habitats

Species	Ecological Setting/Growth Requirements	Ecological Functions Provided
Tree species		
Hooker's willow (*Salix hookeriana*)	needs sun and a consistent source of water but is highly tolerant of salty and brackish waters; native to Pacific coast; adaptable to many soil types and physical requirements met by Puget Sound lowlands	highly attractive to pollinators; creates additional habitat features for birds and rodents; provides shade to decrease water temperatures during summer months
Black cottonwood (*Populus balsamifera*)	prefers moist, not saturated, and sandy or well-draining soils	provides shade to decrease water temperatures during summer months, increasing habitat; provides fast growth and shore stabilization; will aid in future LWD recruitment; popular among pollinators; large tree that would provide roosting habitat for large birds when mature
Pacific madrone (*Arbutus menziesii*)	low soil moisture tolerance; prefers full sun; high tolerance of rocky and sandy soil and disturbance events; likely most suitable for planting at the upland fringe of the riparian area, in areas with dry, sandy soil	roosting habitat and year-round shade
Pacific crabapple (*Malus fusca*)	grows at the edges of estuaries and wetlands and in moist woods	deer browse (leaves); may host butterfly larvae (on leaves); flowers important to pollinators such as mason bees; fruit eaten by birds and other animals; provides cover for wildlife (Native Plants PNW 2014)
Oregon ash (*Fraxinus latifolia*)	prefers highly organic, saturated to wet soils	nesting site for birds, including cavity nesters.
Red alder (*Alnus rubra*)	high soil moisture tolerance; low shade tolerance; high tolerance of different soil types and physical damage/disturbance	forms a symbiotic relationship with actinomyces that creates nitrogen-rich soil; fast-growing species that can aid in future LWD recruitment; does extremely well in disturbed settings
Shore pine (*Pinus contorta*)	highly adaptable; tolerates low nutrient conditions and a variety of soil types; tolerant of salt spray	evergreen tree providing shade and cover year-round; cones provide food source for small mammals and birds
Sitka spruce (*Picea sitchensis*)	prefers moist or well-draining soil, so well suited to a slight elevation	evergreen tree providing shade and cover year-round
Shrub species		
Tall Oregon grape (*Mahonia aquifolium*)	tolerant of shade and a variety of hydrologic conditions	fruits eaten by birds
Nootka rose (*Rosa nutkana*)	prefers open habitats with plenty of sunlight; less tolerant of wet and saturated soils	fruits consumed by birds; flowers attractive to pollinators species; dense, thorny growth helps reduce disturbance by humans

Species	Ecological Setting/Growth Requirements	Ecological Functions Provided
Oceanspray (*Holodiscus discolor*)	common understory shrub; prefers slightly raised topography where soil is moist but not saturated; high tolerance for salt spray	important pollinator plant for bees and other insects
Salal (*Gautheria shallon*)	found in forested wetlands; low tolerance for saturated roots and prefers raised topographical features. Prefers full to partial shade.	fruits consumed by birds and other wildlife; twigs and leaves browsed by deer
Vine maple (*Acer circinatum*	prefers soils that are moist but not consistently saturated for long periods of time	effective physical buffer preventing humans from entering wetlands; seeds and buds consumed by small rodents and birds; dense root mat provides erosion control on steep banks
Snowberry (*Symphoricarpos albus*)	tolerates moist soils in northern parts of the Puget Sound Basin; prefers bright areas but tolerates filtered light when in an understory	fruits and seeds consumed by birds
Osoberry (*Oemleria cerasiformis*)	tolerant of both saturated and dry soils; tolerates partial shade	fruits consumed by birds; twigs and bark used as nesting material
Thimbleberry	prefers open sites like forest clearings and shorelines, or the understory of open forests dominated by deciduous trees like red alder; inhabits moist to dry sites	a preferred food source of Columbia black-tailed deer; berries eaten by birds and other wildlife; thimbleberry thickets provide ideal nesting and cover habitat for birds and other wildlife
Bracken fern (*Pteridium aquilinum*)	prefers moist to dry soils and shady conditions	creates cover for small birds and mammals
Red-osier dogwood (*Cornus stolonifera*)	tolerant of saturated soils and fluctuating water tables; prefers wetland margins; associated with black cottonwood and red alder; often found in nitrogen-rich alluvial floodplain forests	wildlife browse twigs, foliage, and fruits; shrubs provide excellent nesting habitats for songbirds
Black twinberry (*Lonicera involucrata*)	prefers wet forest and shrub communities; prefers full sun to partial shade	wildlife browse; nesting material for small birds and mammals
Sweetgale (*Myrica gale*)	prefers lowland coastal marshes and full sun with wet soil; found in wetlands and the upper fringes of salt marshes	nitrogen fixer; fruit consumed by beaver and, in small quantity by birds
Herbaceous species		
Pacific silverweed (*Argentina egedii)*	occurs at higher elevation in tidal marshes (at or above mean high water mark); salt water tolerant; prefers open sites	seeds consumed by song birds; provides some erosion control
Lyngbye's sedge (*Carex lyngbye*i)	occurs in saline environments; prefers moist and wet soil; intolerant of shade and drought; prefers fine, silty soils to sandy soils	pioneer species that colonizes open and newly disturbed habitat; heavily grazed by geese during spring migration as well as by trumpeter swans
Seaside plantain (*Plantago maritima*)	prefers sandy soil; adapted to saline conditions and full sun	grazed by waterfowl and other herbivorous birds

Species	Ecological Setting/Growth Requirements	Ecological Functions Provided
Seaside arrowgrass (*Triglochin maritima*)	tolerates salty and brackish tidal marshes; prefers slightly elevated soils	edible seeds eaten by birds observed in marsh; grazed by waterfowl and other herbivorous birds
Pickleweed (*Salicornia sp.*)	prefers sandy substrate and salty marshes with regular tidal inundation	grazed by waterfowl and other herbivorous birds
Seashore saltgrass (*Distichlis spicata*)	prefers wet and inundated soils and emergent, sunny conditions	provides erosion control; highly productive in salty conditions
Alkali grass (*Puccinellia sp.*)	temperate species that prefers wet soils; grows well in saline conditions	provides erosion control, habitat complexity, and biodiversity
Coastal strawberry (*Fragaria chiloensis*)	prefers sandy and well-drained soil	provides erosion control; consumed by birds
Fat-hen saltbrush (*Atriplex patula*)	grows in upper topography of salt marshes; tolerates heavy inundation and saline conditions	grazed by waterfowl and other herbivorous birds
Puget Sound gumweed (*Grindelia integrifolia*)	prefers full sun; grows in variety of substrate but prefers coarser soil	provides habitat complexity and biodiversity
Baltic rush (*Juncus balticus*)	prefers damp soils all year; tolerates saline conditions	provides erosion control and sediment retention
Slough sedge (*Carex obnupta*)	prefers wet to damp soils; tolerates shady conditions	found in upper reaches of tidal marshes; grazed by birds

Sources: Cooke (1997); Pojar and MacKinnon (2004); USDA (2019)
LWD – large woody debris

Within the Marsh, herbaceous species such as Pacific silverweed, Baltic rush, Lyngbye's sedge, pickleweed, seashore saltgrass, and Puget Sound gumweed have been observed during baseline monitoring efforts. These salt-tolerant herbaceous species, along with seaside plantain and coastal strawberry, would be suitable for the lower parts of the buffer areas, nearest the stream channel or Marsh edge.

Dense plantings of trees and shrubs should be installed along the restored Willow Creek channel in order to provide a robust buffer that will shade the creek and help prevent human disturbance of the stream channel. Shrub species such as sweetgale, osoberry, oceanspray, Nootka rose, and tall Oregon grape prefer wet soils and could be planted near the lower portions of the buffer zones. At slightly higher elevations, plantings of Hooker's willow, shore pine, and Sitka spruce would be suitable. These plantings will provide habitat for insects, some of which will fall into the water, providing food for salmon and other fish in the channel. Dense riparian vegetation will also provide habitat and food for native birds, who will forage upon the fruits, seeds, and/or vegetative growth of many of the species (Table 7).

The space that will be available for riparian buffer plantings on the northwest side of the daylighted Willow Creek channel is very narrow (Figure 3). For this reason, species for this area should be selected carefully. Because they will have little surrounding vegetation to help provide shade, and because soils here are likely to be dry and compacted (as this area is very near the BNSF right-of-way), hearty species that can tolerate full sun, such as common snowberry, should be selected. Additionally, plants in this area may need to have relatively compact growth forms in order to prevent them from growing to a size that would interfere with the railway right-of-way. The goal should be to select plants that can tolerate the growing conditions and remain within their limited footprint, but also provide shade and cover over the creek channel as much as possible.

It is anticipated that it will be possible to plant scrub-shrub and groundcover vegetation on the interior (Marsh-facing) side of the flood walls. Such plantings could provide a visual screen between, for example, Shellabarger Marsh and SR-104, as well as help prevent disturbances of the Marsh. Because the berms will provide elevated topography, shrubs like tall Oregon grape, Nootka rose, salal, and osoberry would be suitable candidates for planting on the flood walls. Herbaceous species like slough sedge and coastal strawberry could provide ground cover.

All plants installed as part of the Project will likely need to be irrigated for the first two to three years after restoration. The exception would be any plants installed very near the Marsh or stream edge, where soils remain saturated year-round. Regardless, all plantings should be monitored (as discussed in Section 5.4) for drought stress in order to decide when and where to irrigate. A thick layer of coarse wood chip mulch around plantings would also help reduce drought stress by maintaining soil moisture and reducing weed growth.

5.3 Recommendations for Control of Cattail and Phragmites

The eastern lobe of the Marsh is dominated by cattail (*Typha* spp.) (Figure 2), and there are two patches of common reed growing in the western estuarine portion of the Marsh. Control of both of these species will likely be required in order to help the Marsh reach its full restoration potential as the Project is implemented.

Cattail tend to become invasive in wetlands when wetlands are disturbed by changes in hydrology, nutrient levels, and/or salinity, often resulting in dense, monotypic cattail stands (Stevens and Hoag 2006). The seeds and seedlings of cattail have low salinity tolerances, while the older, rhizome-bearing plants are salt tolerant (Beare and Zedler 1987). It can become necessary to control cattail in a wetland system in order to allow other plants to re-colonize areas dominated by cattail. Cutting or mowing cattails can be an effective control measure that does not require the use of herbicides. Cattail should be cut or mowed in late summer with a powered weed trimmer or shears, and if possible, the plants should be cut below the water line (Ochterski 2015). After Willow Creek has been daylighted and full tidal flow is once again allowed into the Marsh, water levels in some areas currently dominated by cattails will likely rise, providing opportunities for cattail control.[10] Cut cattail leaves and flower spikes should be removed from the Marsh and properly composted or otherwise disposed of off-site, if possible. Cattail stands may need to be mown or cut multiple times over a number of years in order to achieve control.

Common reed is a very tall grass (reaching heights of up to 4 m [13 ft]). It is listed as a Class B noxious weed in Snohomish County and control is required. Common reed patches can expand rapidly through both rhizomes and stolons, and the plant is highly salt tolerant and can withstand frequent and prolonged flooding (Tilley and St. John 2012). Herbicide (i.e., glyphosate) applications in the late summer or early fall are the recommended treatment for common reed. Cutting before herbicide application may be beneficial; any cutting of common reed canes should be performed in late July (King County 2010). Herbicides can be applied to cut stands of reed or as a foliar spray, and treatments may need to be repeated for several years in order to achieve complete control of a stand. Any herbicide application should be performed by a licensed applicator following all rules and regulations. Any control of common reed should be conducted carefully in order to avoid spreading fragments of the stems, rhizomes, or stolons, thereby preventing additional spread of the plant. Cut plants should be bagged and disposed of, not composted.

5.4 Recommendations for Post-restoration Monitoring

It is currently not known what type of formal post-restoration monitoring requirements, if any, the City will need to comply with in association with the Project.

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[10] While cattail prefer saturated soils and shallow water, they generally do not grow in water deeper than 1.5 ft (Ochterski 2015).

However, habitat monitoring provides extremely useful information that helps to guide maintenance activities and track how well a site fulfills its restoration goals. The Project will create new habitat areas like the daylighted creek channel, and it will enhance existing habitat within the Marsh. A year-long baseline monitoring study documenting conditions within the Marsh and its buffer areas is currently underway (Windward 2018). Therefore, the primary recommendation related to post-restoration monitoring is to repeat the baseline study after the Project has been constructed. Repeating the baseline study several times, and at different time steps (e.g., one year after Project construction, three years after Project construction, etc.), would provide an understanding of how habitats within the Project footprint change and mature over time. The following subsections provide additional ideas for post-restoration monitoring that could be conducted primarily in areas downstream from the Marsh that were not covered in the Marsh baseline monitoring study.

5.4.1 Large woody debris monitoring

After Project construction, pieces of LWD installed within the restored creek channel or the Marsh should be monitored, primarily to detect any major shifts in the position or location. This monitoring will ensure that the LWD structures are stable and functioning as planned. The Marsh baseline monitoring plan includes methods for monitoring LWD in buffer zones and in the Marsh; these methods could be adapted as necessary to help monitor LWD installed as part of the Project (Windward 2018).

LWD surveys could be conducted in late summer to early autumn (i.e., when stream flows are generally lower and allow installed LWD pieces to be more visible) in order to confirm the locations of LWD, determine whether any pieces are moving or causing problems such as bank erosion, and check the level of decay (referred to as decay class) of the wood. In monitoring plans developed for habitat mitigation projects in the Puget Sound area, it is common to monitor LWD 1, 2, 3, 5, 7, and 10 years following restoration. A similar temporal scheme could be used to monitor this Project. In addition, a qualitative assessment of LWD stability and function could be conducted during two peak-flow events in the first winter following construction. Such monitoring would allow the City to identify any pieces of LWD that may have moved or migrated downstream since construction. As-built drawings created immediately after Project construction could also be used for comparison to help identify pieces of LWD that may have migrated. LWD movement is important to monitor, particularly in developed environments, where dislodged pieces of LWD can cause damage to or blockages of downstream structures such as bridges. Monitoring LWD after construction would allow the City to plan appropriate maintenance actions if any piece of LWD is of concern.

5.4.2 Planted vegetation survivorship monitoring

One of the most important aspects of vegetation monitoring is assessing plant health and survivorship in the first few years after installation. Such monitoring allows for the identification of any stressors, such as drought or disease, which may affect the health of the plantings; any issues can then be addressed in a timely manner, maximizing survivorship rates and reducing the need for re-planting. It is recommended that assessments of the survival of all planted vegetation be conducted once per year, during the middle or later part of the growing season, for at least the first three years after planting to assess the health of the plant community and determine whether maintenance actions will be required.

Plant survivorship could be monitored quantitatively using monitoring plots to survey a subset of the installed plants, or qualitatively using site-wide walk-through surveys. Within monitoring plots, the number of live stems could be compared to the actual stem densities planted in order to calculate the percentage of installed vegetation that survived. Qualitative walk-through surveys could be performed to quickly evaluate the condition of all plantings; such surveys may be the easiest and most efficient method to employ within small planting areas like the riparian buffer area on the northwest side of the daylighted creek channel. Qualitative surveys are meant to identify threats to plant survival rapidly so that they may be addressed through maintenance activities in a timely fashion, thereby reducing the number of mortalities. Maintenance activities may include the addition of herbivory protections like tree tubes, extended irrigation, or changes in plant species composition, if necessary, to improve plant survival. It is common to have to conduct some replanting within the first few years post-restoration.

5.4.3 Plant community and percent cover monitoring

Species abundance and percent cover surveys could also be conducted to evaluate overall plant community development throughout the buffer areas. Such surveys are often conducted once per year in summer (to capture peak growing conditions) 1, 2, 3, 5, 7, and 10 years following restoration. The buffer vegetation survey methods detailed in the Marsh baseline monitoring plan (Windward 2018) could be employed for this effort as well. All vegetation—including planted vegetation, existing vegetation, and vegetation that was naturally recruited following restoration—would be evaluated and identified to the species level, if possible. A measurement of the percent cover of each vegetation layer (herbaceous, shrub, and tree) would be collected.

Data from these surveys would allow the City to determine whether revegetation goals for the riparian buffer areas are being met. If plant community composition or percent cover goals are not being met, or if threats to the desirable plant community are identified (such as the presence of invasive weeds), maintenance activities could be initiated.

5.4.4 Fish presence monitoring

Several different methods could be used to monitor for the presence of fish in the Marsh system after the Project is constructed. It is recommended that the methods used incorporate either passive monitoring for fish (simply making visual assessments within the stream and tidal channels,) or a catch-and-release system that is non-lethal to fish. Such methods may include small-net beach seining, and deploying fyke nets. A small-net beach seine uses a mesh knotless nylon net deployed in "round haul" fashion: fixing one end of the net on the beach while deploying the other end by wading upstream against the water current, then returning to the shoreline in a half circle (Beamer et al. 2006). The ends of the net are then retrieved to yield the catch. Fyke nets are used to sample smaller, tidal stream channels that are less conducive to beach seining. Fyke nets are mesh knotless nylon nets with a cone sewn into the net to collect fish draining out of the channel. Net dimensions are variable depending on the stream channel's cross-sectional dimensions and are sized to completely block fish access during a high tide. The net is set across the channel at high tide and fish are caught during the ebb tide (Beamer et al. 2006). The species, count, approximate size, and location of all fish caught would be recorded to the extent possible to provide a detailed picture of which fish are using the Marsh system and at which life stages. Fish caught in the nets would be handled minimally prior to release at the site of capture. However, if necessary, fish may be placed in a holding tank with an aeration pump for a short period to reduce the likelihood of recapturing fish, and to allow time for more accurate recordkeeping.

Surveys should be conducted at times of the year when juvenile salmonids would be most likely to use the Marsh system for rearing and feeding activities (e.g., spring and summer for Chinook, spring for coho, and summer and fall for chum). Fisheries biologists with the Tulalip Tribe or a similar entity could also be consulted each year prior to survey initiation to determine the optimal start time for surveys and for assistance with survey methods.

All necessary permits would be obtained prior to conducting any the fish surveys. In addition to the scientific collection permit (issued by Washington State Department of Fish and Wildlife) required for the collection and handling of any wildlife, an Endangered Species Act Section 10 scientific research permit/4d approval (issued by National Marine Fisheries Service) would be required for all collection surveys that include anadromous fish such as salmonids, even if the surveys conducted are solely catch and release.

Although fish presence is influenced predominantly by large-scale ecological factors that are not limited to the boundaries of the Marsh and its tributary creeks, fish surveys would provide a sense of the accessibility and suitability of the restored habitat for native fish species. Monitoring plans for mitigation sites in the Puget Sound Region often require fish surveys to be conducted 1, 2, 3, 5, 7, and 10 years following restoration. A similar temporal scheme could be used for this Project.

Fish stranding surveys could also be conducted to ensure that newly created habitat features and connections are not trapping fish (e.g., new off-channel habitat that fish can access during high tide/high freshwater flows but that are cut off for extended periods of time from tidal and stream channels during low tide/low freshwater flows). The goal of these surveys would be to identify areas that may inadvertently be trapping fish and causing mortality, rather than areas where fish may be temporarily "stranded" throughout the tidal cycle but ultimately able to exit. Fish stranding surveys could be conducted by visually assessing off-channel areas at times of year that juvenile salmonids are known or expected to use the Marsh system. If fish were observed to be stranded in certain areas, adaptive management actions could be taken to reduce the occurrence by either improving low-flow connections between the main channel habitat and off-channel habitat, or by more fully restricting fish access to certain areas if they are not appropriate for off-channel fish habitat.

6 Summary

The Project will protect and enhance the ecosystem services provided by the Marsh and its tributary creeks. This would be a worthwhile endeavor, given the rarity of nearshore estuarine pocket marshes in the vicinity of Edmonds and the importance of this kind of habitat to juvenile salmonids and other fish and wildlife species. Based on the modelling analysis described in this document, the Project has the potential to increase the level of ecosystem services provided by the Marsh and its tributary creeks by approximately 62%, as well as to protect the current level of functions being provided by the Marsh.

In addition to providing enhanced habitat functions beneficial to fish and wildlife, a restored Marsh system would provide the City, as well as the larger community, the opportunity to observe and appreciate the roles that nearshore estuarine marshes, tidal streams, and adjacent riparian forests play in fostering the native flora and fauna of the Pacific Northwest, and how they can do so even within an urban area.

7 References

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Appendix A. Habitat Equivalency Analysis Overview

Habitat Equivalency Analysis: An Overview

Damage Assessment and Restoration Program
National Oceanic and Atmospheric Administration
Department of Commerce

March 21, 1995
(Revised October 4, 2000)

1. Introduction

1.1 Goals of the paper

Natural resource trustees are authorized to act on behalf of the public to protect the resources of the nation's environment. Serving as a trustee for coastal and marine resources, NOAA determines the damage claims to be filed against parties responsible for injuries to natural resources resulting from discharges of oil, releases of hazardous substances, or physical injury such as vessel groundings.[1] Habitat equivalency analysis (HEA) is a methodology used to determine compensation for such resource injuries. The principal concept underlying the method is that the public can be compensated for past losses of habitat resources through habitat replacement projects providing additional resources of the same type. Natural resource trustees have employed HEA for groundings, spills and hazardous waste sites. Habitats involved in these analyses include seagrasses, coral reefs, tidal wetlands, salmon streams, and estuarine soft-bottom sediments.

The goals of this paper are to present an overview of HEA and illustrate the method with a simple, hypothetical example. In section 1.2 below, we outline briefly the natural resource damage context for HEA applications and the conditions for use of HEA. An example of how HEA is used to estimate the appropriate level of compensation for injuries to natural resources is presented in section 2. Appendices A through C present an algebraic representation of the HEA calculations and provide detailed tables from the example.

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[1] The Under Secretary for Oceans and Atmosphere (NOAA Administrator) acts on behalf of the Secretary of Commerce as a Federal trustee for natural resources under the Comprehensive Environmental Response, Compensation, and Liability Act ("CERCLA"; 42 U.S.C. § 9601 *et seq.*), the Clean Water Act (33 U.S.C. § 1251 *et seq.*) , the National Marine Sanctuaries Act (16 U.S.C. § 1431 *et seq.*), and the 1990 Oil Pollution Act ("OPA"; 33 U.S.C. § 2701 *et seq.*).

1.2 Use of HEA in natural resource damage assessments

Natural resource damage claims have three basic components: (1) the cost of restoring [2] the injured resources to baseline, or "primary restoration," (2) compensation for the interim loss of resources from the time of injury until the resources recover to baseline *plus* (3) the reasonable costs of performing the damage assessment.[3] Following statutory requirements, all recovered damages are used to restore, replace, rehabilitate or acquire the equivalent of the injured resources (or to cover the costs of assessments). Consequently, recoveries for interim losses are spent on "compensatory restoration" actions providing resources and services equivalent to those lost. To ensure full compensation for interim losses, the trustees determine the scale of the proposed compensatory restoration actions for which the gains provided by the actions equal the losses due to the injury. The damage claim then is the cost of implementing the selected primary and compensatory restoration actions (plus the costs of the assessment) or alternatively, the responsible parties may be allowed to implement the projects themselves, subject to performance criteria established by the trustees. To develop the restoration plan, trustees must determine and quantify injury, develop restoration alternatives that consist of primary and compensatory actions, scale restoration alternatives, and select a preferred restoration alternative. This paper examines a method for scaling restoration alternatives, HEA.[4]

For compensatory restoration actions, the scaling question is: what scale of compensatory restoration action will compensate for the interim loss of natural resources and services from the time of the incident until full recovery of the resources? The scale of compensatory restoration actions is conditional upon the choice of primary restoration actions. Consequently, for each restoration

[2] Restoration refers to human actions taken after the removal of the cause of injury (e.g., after remediation of a hazardous waste site, removal of the vessel in the event of a grounding), to return an injured resource to its pre-injury conditions. We use the term in its broad sense, to encompass the statutory concepts of "restoration, rehabilitation, replacement, and/or acquisition of the equivalent" of the injured resources.

[3] At any point in time, baseline refers to the condition of the natural resources and services that would have existed had the incident not occurred. If the resources are not expected to recover fully, interim losses will be calculated in perpetuity.

[4] This description characterizes the process outlined in the natural resource damage assessment (NRDA) regulations implementing OPA (15 CFR Part 990) and in the proposed statutory changes to the CERCLA NRDA provisions (43 CFR Part 11).

alternative under consideration, the type and scale of the primary restoration actions are to be identified first.[5] Then the compensatory components of restoration alternatives can be scaled.

The process of scaling a project involves adjusting the size of a restoration action to ensure that the present discounted value of project gains equals the present discounted value of interim losses. There are two major scaling approaches: the valuation approach and the simplified service-to-service approach, which applies under certain conditions.

HEA is an example of the service-to-service approach to scaling. The implicit assumption of HEA is that the public is willing to accept a one-to-one trade-off between a unit of lost habitat services and a unit of restoration project services (i.e. the public equally values a unit of services at the injury site and the restoration site).[6] HEA does not necessarily assume a one-to-one trade-off in resources, but instead in the services they provide. Consider a marsh as the resource and primary productivity a resource service. Suppose the replacement project provides only 50 percent of the productivity per acre of marsh as the injured site would have provided, but-for the injury. In order to restore the equivalent of lost productivity per year, then, the replacement project requires twice as many acres of marsh. Habitat equivalency analysis is applicable so long as the services provided are comparable.

The assumption of comparable services between the lost and restored habitats may be met when, in the judgment of the trustees, the proposed restoration action provides services of the same type and quality, and of comparable value as those lost due to injury. In this context, there is a one-to-one tradeoff between the resource services at the compensatory restoration site and the injury site. Therefore, the scaling analysis simplifies to determining the scale of a restoration action that provides a quantity of discounted replacement services equal to the quantity of discounted services lost due to the injury.

In cases where services at the compensatory restoration site are not of the same type and quality or of comparable value to those injured, then the assumption of a one-to-one trade-off

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[5] This includes identifying the recovery trajectory from primary restoration.

[6] The concept of services refers to functions a resource serves for other resources and for humans. For example, a wetland habitat may provide on-site ecological services such as faunal food and shelter, sediment stabilization, nutrient cycling, and primary production. Off-site services may include commercial and/or recreational fishing, bird watching along the flyway, water quality improvements due to on-site water filtration, and storm protection for on-shore properties due to the creation of wave breaks. Human services include both use and non-use services, so the HEA approach measures and accounts for non-use services in the damage claim.

between the resources at the injury site and the compensatory restoration site may be inappropriate. In these cases, NOAA recommends that trustees evaluate whether the conditions for HEA are met and consider using the valuation approach as an alternative to determining the trade-off between injuries and compensatory restoration actions.

Necessary conditions for the applicability of HEA include that (1) a common metric (or indicator) can be defined for natural resource services that captures the level of services provided by the habitats and captures any significant differences in the quantities and qualities of services provided by injury and replacement habitats, and (2) the changes in resources and services (due to the injury and the replacement project) are sufficiently small that the value per unit of service is independent of the changes in service levels. [7] When choosing a metric to evaluate the quantity and quality of services provided per unit of habitat, the trustees should examine the *capacity, opportunity* and the *payoff* (*i.e.* benefits) of the services being provided as well as *equity* issues involved with the potential compensation projects (*i.e.* who loses and who gains as a result of the injury and the potential compensation projects). *On-site biophysical* characteristics (e.g., soil, vegetative cover, and hydrology) affect the *capacity* of an ecosystem to provide ecological and human services. *Landscape context* affects whether the ecosystem will have the *opportunity* to supply many of the ecological and human services and strongly influences whether humans will value the opportunities for services.[8]

Consider, for example, the wetland function of sediment trapping. A wetland's capacity to provide this function depends on such factors as slope and vegetative cover. The opportunity for the wetland to trap sediments depends on the expected flow of sediments from adjacent land, which will depend upon types of upland land uses (i.e., landscape context). The total value generated from water quality improvements due to sediment trapping will depend upon the uses

[7] A counterexample shows when this condition is not satisfied. Consider the value of harvesting another salmon when salmon are in abundant supply versus the value of another salmon when the harvest has failed in Alaska. The value of providing another pound of salmon may be substantially greater when the salmon are in scarce supply, all else equal.

[8] For a further discussion of these issues, see, *Scaling Compensatory Restoration Actions, Guidance Document for Natural Resource Damage Assessment Under the Oil Pollution Act of 1990,* National Oceanic and Atmospheric Administration, Damage Assessment and Restoration Program, 1997 and King, Dennis M., *Comparing Ecosystem Services and Values,* Report prepared for the National Oceanic and Atmospheric Administration, Damage Assessment and Restoration Program, January 1997.

of the affected downstream water bodies: the value will be greater if there are nearby shellfish beds and finfish spawning areas than if the water flows into a fast-moving river.

The choice of a metric to characterize services is key to determining whether HEA is applicable in a given context. On-site ecological attributes, such as stem density, canopy structure (density times height), or fish density, are sometimes used as a proxy for services; however, they are primarily indicators of *capacity*. It is critical to evaluate the role of landscape context to evaluate the *opportunity* to provide off-site, as well as on-site, ecological and human services.

2. Habitat Equivalency Analysis: An Example

In this section we provide a simplified example to illustrate the method. To complement the example, we provide the algebraic formula for solving an HEA in Appendix A.

We construct the following hypothetical scenario. [9] A heavy fuel oil released from a grounded tanker covered 20 acres of marsh composed primarily of smooth cordgrass (*Spartina alterniflora*) in 2000. The oil smothered significant portions of the marsh, penetrating the sediments in many areas and killing much of the biota. This injury impairs the function of the marsh habitat; the marsh provides food and shelter for animals, water quality improvements for downstream resources, shoreline stabilization and other natural resource services. In addition, the loss of marsh affects human services. For example, marsh habitat supports off-site human services through the production of fish that provide recreational and commercial services and through nutrient filtration that provides water quality enhancement.

Trustees identified a feasible restoration action for compensation: transplanting *Spartina alterniflora* at the injury site for primary restoration and transplanting *Spartina alterniflora* along with some minor regrading at a nearby site. The projects are expected to restore the same type and quality of resources and services. Further, given the similar landscape context of the injury and restoration sites, the trustees judged the projects would restore resources and services of comparable value as those lost.

Under these conditions, HEA applies as a framework for scaling compensatory restoration. The basic steps for implementation include:

[9] The size and the description of the hypothetical injury are not based on actual events and have been chosen simply to demonstrate the HEA calculation.

1. Document and estimate the duration and extent of injury, from the time of injury until the resource recovers to baseline, or possibly to a maximum level below baseline;
2. Document and estimate the services provided by the compensatory project, over the full life of the habitat;
3. Calculate the size of the replacement project for which the total increase in services provided by the replacement project equals the total interim loss of services due to the injury; and
4. Calculate the costs of the replacement project, or specify the performance standards in cases where the responsible party will be implementing the compensatory habitat project.

In the first two steps, trustees must specify numerical values for ecological parameters for both the injured site and the compensatory project site. For each point in time at both sites, the level of services must be characterized as a percent of the baseline level of services at the injured site. As previously noted, the baseline of services is the level of services that would have been provided at the injured site *but-for* the injury. In our example, we assume that local experts consider grass shrimp (*Palaemonetes pugio*) to be a very important (or key) species in this habitat and they believe that the presence of grass shrimp is highly correlated with many services provided by the marsh. The presence and density of grass shrimp may indicate the general health of the marsh vegetation and the availability of food for higher trophic levels. Therefore, we assume that service levels for the injured site and for the compensatory project site are a function of the baseline mean density of grass shrimp in the marsh. Studies indicate that the spill reduced the mean density of grass shrimp by approximately 50%. Using the mean density of grass shrimp as a metric for marsh services, we assume that the service level of the injured marsh prior to any restoration actions is 50% of its baseline service level. [10]

[10] Depending on the exact nature and extent of an injury, the mean density of grass shrimp relative to the baseline density may or may not serve as a good metric for the services provided by the marsh. Additional potential indicators of marsh services might include macrofaunal abundance, fish utilization, vegetative density and percent vegetative cover.

In step three, we calculate the size of the compensatory project for which the total increase in services provided by the replacement project just equals the total interim loss of services due to the injury. Because losses and gains are occurring in different years, we discount the losses and gains so that units reflect what they are worth in the present year, 2000. This makes units from different time periods comparable. The discount rate incorporates the standard economic assumptions that people place a greater value on having resources available in the present than on having their availability delayed until the future. [This process is analogous to financial calculations where, if a dollar is put into the bank today at 3% interest, there will be $1.03 in one year. A person is willing to deposit money in such an interest bearing account only if having $1.03 is (at least) as good as having $1 today.]

The annual discount rate used in a HEA calculation represents the public's preference towards having a restoration project in the present year, rather than waiting until next year. The economics literature supports a discount rate of approximately 3%. [11]

We list below the parameters necessary to complete a simple HEA.

Injured Area Parameters:

- Baseline level of services at the injury site;
- Extent and nature of the injury: the spatial extent of injury (in acres for example) and the initial reduction in service level from baseline at the injured site (characterized as a percent of the baseline level of services). These parameters may be combined to measure the "effective-acres" of an injury; [12]
- Injury recovery function (with primary restoration or natural recovery): the rate of (incremental) service recovery and the maximum level of services to be achieved (characterized as a percent of the baseline level of services);

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[11] For a further discussion of discounting see: National Oceanic and Atmospheric Administration (1999) *Discounting and the Treatment of Uncertainty in Natural Resource Damage Assessment*. Damage Assessment and Restoration Program, Damage Assessment Center, Resource Valuation Branch. Technical Paper 99-1. Silver Spring, MD, February.

[12] Effective-acres may be illustrated with an example. If 30% services remain on an injured 100 acre site, the injury totals 70 effective-acres (100 * (1-0.3) = 70). Note that the percent is represented by its decimal equivalent.

- Recovery period for injured resources: the dates when recovery starts and when maximum level of services will be achieved.

Replacement Area Parameters:

- Initial level of services at the replacement project site, as measured in effective-area (as a percent of baseline services at injury site);
- Replacement project maturity function: the rate of (incremental) service growth and the maximum level of services at the replacement project site (as a percent of the baseline level of services at injury site);
- Maturity period for replacement resources: the dates when services begin to increase and when the maximum level of services will be achieved;
- Replacement/creation project duration: lifetime of increased services.

Discount Rate

- Annual real discount rate

In the following section, we walk through the each of the steps and show how ecological parameters are developed from the injury and how the HEA equation is solved.

Step 1: Quantifying the losses from the injury. For our example, parameter values characterizing the injury are listed in the table below. As shown, we denote the injury to 20 acres of marsh function by specifying that, after injury, 20 acres provide 50% of the services relative to baseline at the time of the injury (2000). The site is projected to maintain a 50% service level until the primary restoration project (transplanting *Spartina alterniflora* at the injury site) is completed in 2001. The injured area is then projected to recover in eight years following a linear growth path to baseline.[13]

[13] The length and shape of the recovery function are chosen in order to simplify the presentation. An alternative recovery function, such as a constant growth rate or other non-linear growth path, and an alternative length of recovery, could be chosen if applicable to the injured resource.

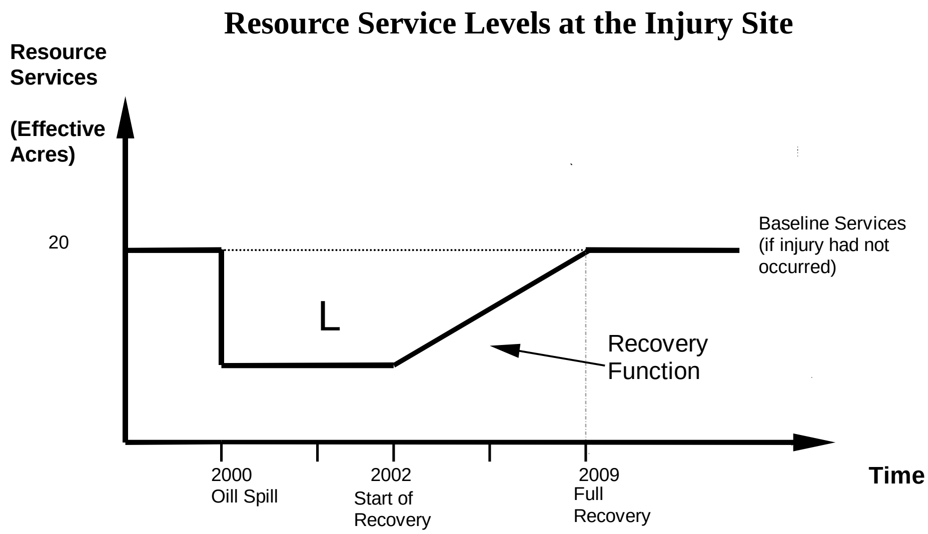
Table 1: Injury Parameter Values

Baseline Information of the Injured Resource:	
Habitat type injured:	Marsh
Year of injury	2000
# of injured acres:	20
Level of services in injury year (relative to baseline services):	50%
Recovery of Injured Habitat following Primary Restoration:	
Year restoration project ends and recovery starts:	2002
Years until full recovery:	8
Services at maximum recovery (relative to baseline):	100%
Shape of recovery function:	Linear
Discount Rate:	
Real annual discount rate	3.0%

The recovery of services provided by the injured habitat is illustrated Figure 1. On the vertical axis is the level of services provided by the injured resource, measured in "effective-acres". The effective-acres of services for a given year represents the product of the percent of baseline marsh services provided by an acre of the injured site times the number of acres injured.[14] When the injury occurs, in year 2000, the number of effective-acres of services drops from 20 to 10, because 50% services remain at the site. Services increase along a linear path beginning in 2002, until full recovery to the baseline at the end of 2009. Interim losses are represented in the diagram by the area labeled "L".

[14] In the multiplication, the percent is represented by the decimal equivalent, so the baseline level of acres is (1.00*20)=20. In 2005, the site is projected to operate at 75% of baseline, so the effective service level is ((1-.75) * 20) = 5.

Figure 1:



To calculate the measure of interim loss in present value terms, we must apply the yearly discount factor to the losses in each year. We calculate an interim loss of 50.84 discounted effective-acre-years by summing over all years of the injury. Appendix B presents the specific steps for calculating the discounted interim loss in services.

Step 2: Quantifying the gains from the habitat replacement project. The parameters characterizing the habitat creation project are listed in the table below. Prior to the compensation project, the nearby site offers 25% marsh services relative to the pre-injured marsh site. Service flows from compensation project commence when the project is completed in 2002. We project that marsh services increase during a 10-year growth period along a linear path and reach a maximum service level equal to 100% of the baseline service level of the injured site. We further project that the site will continue to function at the maximum service level in perpetuity.

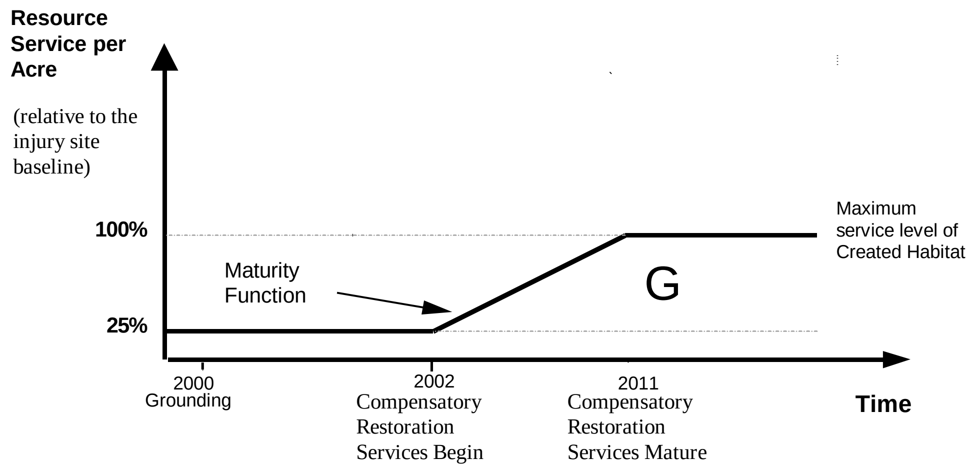
Table 2. Replacement Project Parameters

Replacement Project Characteristics:	
Replacement habitat type:	Marsh
Initial level of services	25%
Year creation/replacement project starts	2001
Year services start increasing	2002
Year in which maximum service level is reached (end of period)	2011
Maximum service level	100%
Shape of recovery function	Linear
Expected length of service increase	Infinity
Replacement Project Comparison Parameter:	
Ratio of maximum services per acre at the compensatory site and the baseline services per acre at injured habitat.	1:1

The increase of services at the habitat creation site is illustrated in Figure 2. The vertical axis measures the services per acre of a replacement project as a percent of the baseline services per acre at the *injured site*. As shown, services begin at 25% and start increasing in 2002, following a linear path until the services reach full maturity in 2011. The services continue to function at the maximum level in perpetuity. The total increase or gain in services per acre, is shown as area “G”, which is the area between the maturity function and the 25% service level.

Figure 2:

Resource Service Levels at Replacement Project Site



To calculate service gains in the present value terms, we must apply the yearly discount factor to the gains in each year and sum over the lifetime of the replacement project. This calculation, presented in more detail in Appendix C, indicates that each acre of replacement project provides 21.32 discounted effective-acre-years of services.

Step 3: Determining the Size of the Replacement Project. To determine the size of the compensatory project needed to compensate for the losses, we divide the total loss in discounted effective-acre-years by the gain per acre of replacement and get 2.38 acres, as outlined in Table 3.

Table 3. **Determining the Size of a Project to Compensate for Interim Losses**

- Injured Area = **20** acres

Present discounted interim losses = **50.84** effective-acre-years (See Appendix B)

- Present discounted lifetime gains per acre of replacement project = **21.32** effective-acre-years per acre (See Appendix C)
- Let **R** = # replacement habitat acres required for compensation.
- Equating lost services and replacement project gains:

  50.84 lost effective-acre-years = **21.32** effective-acre-years/ acre * **R** acres
- *Solving for the size R of the replacement project yields:*

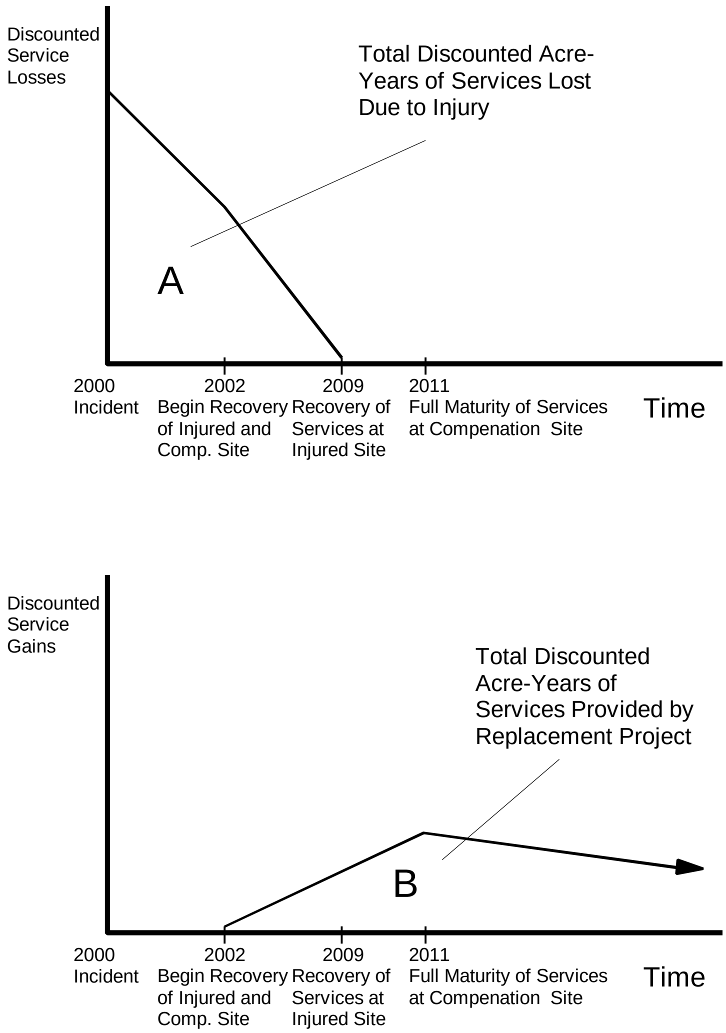
  R = 50.84/21.32

  = 2.38 acres of replacement habitat

The top graph in Figure 3 illustrates the discounted service losses resulting from the injury and the bottom graph illustrates the discounted service gains resulting from the replacement project. At the time of the incident, 2000, service losses occur and, although recovery doesn't start until the year restoration is completed in 2002, the value of future losses decreases in the year 2001 because the losses are discounted. The discounted losses reach zero in the year 2009, when the recovery of services at the injured site is complete. The total discounted service losses are equal to area "A" in the top graph.

The replacement project begins providing service gains in the year 2002, the year the compensation project is completed. In 2011, the compensation project reaches maturity and continues providing services at the same level in perpetuity. However, the value of these services declines over time, eventually approaching a value very close to zero (the value of the service gains approaches zero asymptotically) because the value of service gains is discounted. The total discounted service gains are equal to area "B" in the bottom graph. A replacement project of 2.38 acres will provide just enough service gains to equal the service losses resulting from the injury. That is, area "B" in the bottom graph of Figure 3 is made equivalent to area "A" in the top graph.

Figure 3:



Step 4: Calculating the Cost of the Replacement Project. Step four of HEA, which would be required for any damage assessment and restoration plan regardless of the methodology used in the assessment, occurs after the trustees have calculated the scale of the project. The damages claim is based on the costs of the replacement project.[15] Categories of project costs include the following:

[15] Again, it should be noted that the responsible parties may perform the replacement project, subject to performance criteria established by the trustees.

- planning and design
- environmental impact assessment
- permitting
- construction
- monitoring
- mid-course corrections

Some of the categories of cost can be characterized on a per-acre basis; others impose fixed costs (permitting). We do not calculate project costs in this example.

Appendix A: Algebra of HEA

Below, we outline the generic formula employed to calculate the appropriate scale of the compensation project. We first provide the notation for the HEA calculations.

Let t refer to time (in years), where the following events occur in the identified years:

$t=0$, the injury occurs

$t=B$, the injured habitat recovers to baseline

$t=C$, time the claim is presented (2000)

$t=I$, habitat replacement project begins to provide services

$t=M$, habitat replacement project reaches full maturity

$t=L$, habitat replacement project stops yielding services

Other variables in the analysis include:

V_j , the value per acre-year of the services provided by the injured habitat (without injury)

V_p , the value per acre-year of the services provided by the replacement habitat

x_t^j, the level of services per acre provided by the injured habitat at the end of year t

b^j , the baseline (without injury) level of services per acre of the injured habitat[16]

x_t^p, the level of services per acre provided by the replacement habitat at the end of year t

b^p, the initial level of services per acre of the replacement habitat

r_t , discount factor, where $r_t = 1/(1+r)^{t-C}$, and r is the discount rate for the time period

J, the number of injured acres

P, the size of the replacement project

We select a metric, x, for capturing overall level of habitat services, or habitat function, which could represent a single service flow from the resource or an index that represents a

[16] We simplify the representation of the baseline to be constant through time. Seasonal or inter-annual (or other) forms of variation could be incorporated, by adding time subscripts to the baseline variable b.

weighted average of multiple service flows. In the chosen metric, we define: x_t^j as the level of services per acre provided by the injured habitat at the end of year t, and b^j as the baseline level of services of the injured habitat; consequently, $(b^j - x_t^j)$ is the extent of injury in year t.[17] Analogously, we define x_t^p, as the level of services provided by the replacement habitat at the end of year t, and b^p as the initial level of services of the replacement habitat, prior to any enhancement activities; consequently, $(x_t^p - b^p)$ represents the *increment* in resource services provided by the replacement project - which is the relevant measure for our analysis. In our discussion in the text in the body of this paper, however, we referred to habitat services as a percent of the baseline level of services of the injured habitat, b^j ; in this format, $(b^j - x_t^j)/b^j$ represents the percent reduction in services per acre at the injured site from the injured site baseline, and $(x_t^p - b^p)/b^j$ represents the percent increase in services per acre, relative to the injured site baseline, for the replacement site.

To translate the quantity in year t into an effective quantity in the year of the claim, C, we apply the discount factor $r_t = 1/(1+r)^{t-C}$, where r is the annual discount rate. Finally, the number of injured acres is J. The goal of the habitat equivalency analysis is to solve for the size of the replacement project, P.

[17] For ease of calculation all services flows are calculated from values at the end of each year. More precise estimates of the level of discounted service flows could be obtained by using smaller time periods (e.g. semi-annual or monthly). If smaller time periods are used the discount rate should be adjusted to keep the annual discount rate unchanged.

The equation equating the sum of the present discounted value of the services lost at the injured site with the sum of the present discounted value of the services provided at the replacement site becomes:

$$\left[\sum_{t=0}^{B} V_j * r_t * \left\{\left(b^j - x_t^j\right)/b^j\right\}\right] * J = \left[\sum_{t=I}^{L} V_p * r_t * \left\{\left(x_t^p - b^P\right)/b^j\right\}\right] * P$$

Under the assumption that the per unit value of replacement habitat services, V_p , is equal to the per unit value of injury habitat services, V_j , the calculation to solve for the size of the replacement project then becomes:

$$P = \frac{\left[\sum_{t=0}^{B} r_t * \left(b^j - x_t^j\right)/b^j\right] * J}{\left[\sum_{t=I}^{L} r_t * \left(x_t^p - b^p\right)/b^j\right]}$$

Note that the variables representing the per unit values of services drop out of the equation.

If the per unit values of lost and replacement services are not equal, then an alternative restoration scaling approach may be necessary. The HEA can still be applied if the value differences are known or can be estimated. In that case, the calculation to solve for the size of the replacement project is:

$$P = \frac{V_j}{V_p} * \frac{\left[\sum_{t=0}^{B} r_t * \left(b^j - x_t^j\right)/b^j\right] * J}{\left[\sum_{t=I}^{L} r_t * \left(x_t^p - b^p\right)/b^j\right]}$$

The ratio of $\frac{V_j}{V_p}$ is greater than one if the per unit value of the injured services is greater than the per unit value of the replacement services. Subsequently, more of the replacement project habitat would be needed than if the per unit values were equal. Less of the replacement project habitat would be needed if the per unit value of the injury habitat is less than the per unit value of the replacement habitat.

Appendix B: Interim Losses from a Marsh Oiling

The table below documents the injury and recovery of services on an annual basis and presents the sum of total discounted effective-acre-years lost. The first two columns identify the year and the corresponding status of the primary restoration project. The third column identifies service levels at the injured site as a percentage of the site baseline. Note habitat services grow for eight years following a linear recovery path, starting in 2002. Column four presents the percent service loss at the end of the year. In column five, effective-acres lost per acre are calculated by multiplying the service loss per year (in column 4) times 20, the number of acres injured. In column seven, the discounted effective acres lost are calculated by multiplying the effective acres lost (in column 5) times the discount factor (in column 6). For example, the service level of the injured site was 75% of baseline in 2005. In other words, the loss in services per acre was 25%. The undiscounted effective-acres lost is then 5 (20 acres * 0.25). The discounted effective-acres lost is equal to 4.31 (5 * 0.86).

Interim Losses due to Marsh Injury						
1	2	3	4	5	6	7
Year	Project Status	% Service Level (End of Year)	% Service Loss (End of Year)	Effective Acres Lost	Discount Factor	Discounted Effective Acres Lost
2000		50.00%	50.00%	10.00	1.00	10.00
2001	Primary Restoration	50.00%	50.00%	10.00	0.97	9.71
2002	Recovery Begins	56.25%	43.75%	8.75	0.94	8.25
2003		62.50%	37.50%	7.50	0.92	6.86
2004		68.75%	31.25%	6.25	0.89	5.55
2005		75.00%	25.00%	5.00	0.86	4.31
2006		81.25%	18.75%	3.75	0.84	3.14
2007		87.50%	12.50%	2.50	0.81	2.03
2008		93.75%	6.25%	1.25	0.79	0.99
2009	Recovery Complete	100.00%	0.00%	0.00	0.77	0.00
2010		100.00%	0.00%	0.00	0.74	0.00
2011		100.00%	0.00%	0.00	0.72	0.00
		Total Discounted Effective Acre-Years Lost =				**50.84**

Algebraic notation for table calculations (refer to Appendix A):

Column 3: $\frac{x_t^j}{b^j}$ at end of year

Column 4: $\frac{b^j - x_t^j}{b^j}$ at end of the year.

Column 5: *Column 4 * J*

Column 6: $r_t = \frac{1}{(1+r)^{t-2000}}$

Column 7: *Column 5 * Column 6*

Appendix C: Service Gains from Compensatory Restoration Project

In the table below, the increase in services of the compensatory habitat is calculated per acre of replacement project. The first two columns are the year the project starts, as in Appendix B. The third column identifies service levels at the compensation site as a percent of the baseline service level at the injury site. The forth column indicates the increase in the service level of the habitat for a given year as a percent of the baseline service level at the injury site. We multiply the increase in services per year (column four) times the discount factor (column five) to determine the total discounted effective-acres per acre per year. At the bottom of the table, the total discounted effective-acre-years per acre are summed.

Marsh Services Increase due to Replacement Project					
1	2	3	4	5	6
Year	Project Status	% Service Level (End of Year)	% Service Increase (End of Year)	Discount Factor	Discounted Effective Acres Gained per Acre
2000		25.0%	0.0%	1.00	0.00
2001	Replacement Project Begins	25.0%	0.0%	0.97	0.00
2002	Service Increase Begins	32.5%	7.5%	0.94	0.07
2003		40.0%	15.0%	0.92	0.14
2004		47.5%	22.5%	0.89	0.20
2005		55.0%	30.0%	0.86	0.26
2006		62.5%	37.5%	0.84	0.31
2007		70.0%	45.0%	0.81	0.37
2008		77.5%	52.5%	0.79	0.41
2009		85.0%	60.0%	0.77	0.46
2010		92.5%	67.5%	0.74	0.50
2011	Services Reach Maximum	100.0%	75.0%	0.72	0.54
2012 - "Infinity"	Services Continue in Perpetuity	100.0%	75.0%		18.06
Total Gain in Discounted Effective-Acre Years/Acre =					**21.32**

Algebraic notation for calculations (Refer to Appendix A):

Column 3: $\frac{x_t^p}{b^j}$ at end of year

Column 4: $\frac{x_t^p - b^p}{b^j}$, where $b^p = .25$

Column 5: $r_t = \frac{1}{(1+r)^{t-2000}}$

Column 6: *Column 4 * Column 5*